Data Centres Optimization for Energy-Efficient and EnvironmentalLy Friendly INternet

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Executive Summary

This document is the deliverable D2.1 “Business scenarios and use-case analysis” of Work Package 2 “Business modelling, use-cases, requirements and system architecture” within the FP7-SMARTCITIES-2013 DOLFIN project.

DOLFIN aims to significantly contribute towards improving the energy efficiency of Data Centres and stabilizing of Smart Grids, following a holistic approach, across networks of Data Centres and Smart Grids. DOLFIN will model, monitor, and measure energy consumption and enable seamless, autonomic migration of Virtual Machines (VMs) between servers of the same DC or across a group of Energy-conscious, Synergetic DCs, aiming to:

optimize the overall energy consumption by dynamically changing the percentage of active versus stand-by servers and the load per active server in a DC, and

stabilize the Smart Grid energy distribution, under peak load and increased demand, by dynamically changing the energy consumption/ production requirements of the local DCs.

The main purposes of this deliverable can be summarized in the detailed description of the business scenarios and the use-cases related to DOLFIN project. Such a description has been achieved via a workflow that is outlined in the following:

- Identification of the most typical business objectives for Data Centre Operator
- Identification of the state-of-art of the technology involving Data Centre operations and selection of the most promising technology enablers that will be used in DOLFIN framework
- Definition of the state-of-art of business models for Data Centre Operators
- Definition of actors involved in DOLFIN operation framework
- Business scenario and use-cases definition
- Data Centre Metrics and KPI relevant for DOLFIN project
- Analysis of use-cases using the QFD (Quality Function Deployment) method.

The Business scenario and the use-cases definition achieved comes from real-world considerations, taking into account the state of art of actual Data Centre technologies and business objectives, highlighting on one hand the major drawbacks of actual technologies and on the other hand the potential for the implementation of DOLFIN. The QFD analysis has been introduced to better analyse the correlations between the business objectives/problems and the technology enablers and also between the business scenarios/problem and the technology enablers, to evaluate the impact of each technology enabler to solve each problem as a business objective / scenario objective.

1. Introduction

Data Centres nowadays are consuming enormous and increasing amount of energy, with a significant impact on the environment and the greenhouse emissions. In 2011, Data Centres' total energy consumption was around 271 billion kWh, enough to power up all residential households from industrialized countries such as UK or France, comparable to the total amount of energy consumed by Italy [1] , approximately 7% of the US total energy consumption[2] . Just the Microsoft Data Centre in Quincy (Washington) consumes 48MW, which is enough to power 40.000 homes [3] [4] . The consumption of dozens of MW per Data Centre greatly affects the global economy. Modern Data Centres may have operational costs as high as $5.6M [5] per year, while in 2010 and 2011, US invested approximately $35 billion in Data Centre power consumption. DOLFIN's vision is to significantly contribute towards improving the energy efficiency of Data Centres and stabilizing of Smart Grids, following a holistic approach, across networks of Data Centres and Smart Grids.

For the deployment of a Data Centre, a large investment is requested that will provide a ROI (Return on Investment) over a very long period of time. The ROI issue can be addressed with different strategies, where great deal of forethought and planning is required, taking into account some key items:

- Adequate physical environment
- Power management
- Cooling infrastructure
- Network infrastructure
- Support/Maintenance strategy
- Business Continuity/Disaster Recovery
- Security aspects

Each one of these items is critical for the efficient work of the DC and each one contributes to the achievement of business strategies.

Beside these basic requirements, the DC owners build their business model, introducing a large sets of services that should be supported by the basic DC infrastructure (such as: cloud services, data storage, as well as connectivity services).

A key concept that has emerged in recent years is the use of virtualization systems and services. By consolidating multiple physical bare-metal servers into fewer virtualized machines, Data Centres are improving resource utilizations and reducing operational costs. Virtualization is a very hot topic at the moment. Analysts are talking about it strongly; 36% of organizations are considering it and 19% of organizations are using it [6] . Moreover the new concept of virtualization has also reshaped the business models. It has introduced new elements which take account of the potential arising from the flexibility of virtualized systems. Just to make an example, the whole Cloud paradigm leverages on the possibility to offer services to the end-user based on resources (CPU, Networking, Storage, etc.) that are built as virtual machines over physical servers. An example is a typical computing service (based on the Infrastructure as a Service paradigm) which gives the customer is the ability to manage at runtime its own set of virtual machines, modify their processing capabilities, connectivity as well as installing and removing customer software.

The virtualization topic can be seen as a technology enabler, since it provides the basis for some of the concepts that will be exploited in Dolfin, such as the ability to play with more dynamic SLA (Service Level Agreements) policies among service provider and customer, more precisely, the possibility of defining service agreements characterized by parameters that can be changed dynamically based on specific business policies.

Following the same principle, the aspects related to the concepts of virtualization are taken into consideration in Dolfin with the ultimate goal to leverage and coordinate the various elements of the Data Centres in order to maximize energy efficiency.

This document is structure as follows:

- Chapter 2 presents the rationale behind energy efficiency in Data Centres
- Chapter 3 presents the Data Centres Business Models
- Chapter 4 presents the Data Centres Business Scenarios
- Chapter 5 presents the Use Case descriptions
- Chapter 6 presents Use Cases Analysis using Quality Function Deployment (QFD)
- Chapter 7 presents the evaluation of the system
- Chapter 8 presents the conclusions of this document

2. Rationale behind energy efficiency in Data Centres

2.1. Business Objectives

Considering a Data Centre as a business organisation, it is safe to assume that it targets to provide services that can meet or exceed the expectations of its customers, maximising the utilisation and the efficiency of all the underlying resources. As electric power is a must-have resource for all the operations of a DC, it would be interesting to have a better understanding on how the optimisation of energy consumption would assist a DC Operator to achieve its business objectives, such as:

- Reduce operational costs
- Increase the performance of offered services
- Increase customer satisfaction
- Improve the overall efficiency of the energy system
- Stimulate the adoption of green energy
- Increase the availability and the reliability of DC federation

2.1.1. Data Centre reduce operational costs

Even if each Data Centre is, as a matter of fact, unique in its architecture, footprint and goals, certain group of common characteristics can be drawn in order to trace what can be considered a typical break down for the ownership costs of Data Centre infrastructure. Moreover, we are assuming that all costs related to the initial deployment of the Data Centre itself (CAPEX) will not be considered since DOLFIN interest is concentrated in mitigating and managing OPEX expenses. The following breakdown for operating the Data Centre must be considered:

- Server costs
- Infrastructure costs
- Power costs
- Other costs

Server costs are the first voice to be described since from it is the infrastructure on which the business of the Data Centre is built. The need for the initial investment and subsequent needs to operate, upgrade and maintain during the whole Data Centre lifecycle make this investment one of the most important and most strategic.

By **infrastructure costs**, we mean all costs related to facilities dedicated to consistent power delivery and to evacuating heat. In some sense, infrastructure is the overhead of Data Centres. The main elements composing infrastructure are Chillers, Universal Power Supply (UPS), Power Distribution unit (PDU), CRAC (Computer Room Air Conditioned).

Power costs are one of the most important voices in the cost breakdown for the Data Centre, due to the high cost of energy and to the high load of the Data Centres themselves. Moreover, the energy consumption is foreseen to increase in the next years mainly due to the growth of internet traffic driven by cloud services and internet applications.

Apart from direct costs, **other costs** or **indirect costs** resulting from such territorial policies that require the payment of environmental taxes or similar, should be considered, too.

From DOLFIN point of view the main relevant element to be managed, investigated and mitigated is the costs related to the power usage. A typical breakdown for the power utilization that can help to understand how power consumption is divided among the different infrastructure parts of the Data Centre is showed in Figure 2-1.

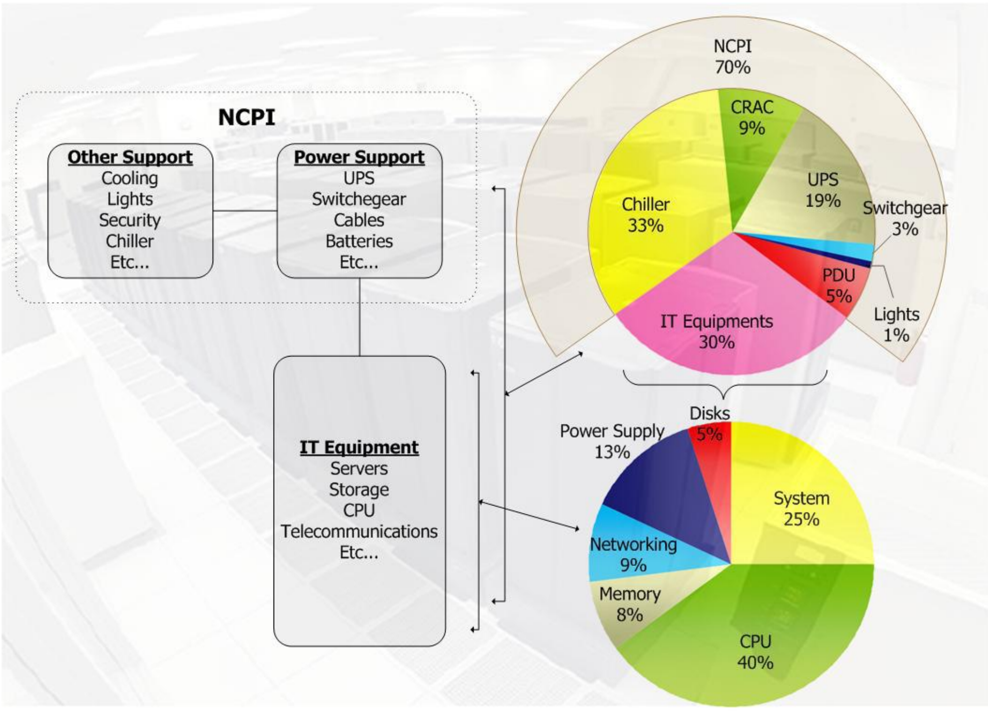

Figure 2-1: Breakdown for Data Centre power consumption

According to Green Grid [7] , power is wasted at different stages of Data Centre operation. A typical breakdown of Data Centre energy overheads, which is also depicted in Figure 2-1, involves:

- Network-Critical Physical Infrastructure (NCPI) equipment, which is responsible for approximately the 70% of total Data Centre energy consumption; 45% of which is due to cooling infrastructure and 25% for power delivery units.
- The remaining 30% of total energy is delivered to IT equipment for critical operations, such as hard disk drive operations, networking, memory, CPU, motherboards, fans, etc.

The analysis of these cost indexes should lead the implementation of strategies for the services deployment, and (in general) for the implementation of the entire DC system that should be conformed to permit the optimization of the global system capacity and DC physical infrastructure. This physical infrastructure needs to be structured appropriately to support the main business activities, respecting also to the real needs and the energy efficiency goal.

The main technology enabler to realize proper management, mitigation and optimization of energy consumption issues has been proven to be the virtualization framework. In that sense, Virtualization perfectly addresses the requirements of energy efficiency in Data Centres. The resources of a Virtual Machine can be provisioned dynamically, as the workload demands change for an application. Virtualization is the most adopted power management and resource allocation technique used by Data Centre operators. It is implemented in both the server and switch domain but with different objectives.

Server domain virtualization usually achieves energy efficiency by sharing limited resources among different applications. On the other hand, virtualization does not provide for energy efficiency in the network domain. In effect, network resources are burdened by the virtualization techniques, since live migration of Virtual Machines between physical hosts generates a significant amount of traffic.

With the physical reduction of the amount of IT equipment, it became possible to optimize power utilization and cooling, minimizing the unused capacity. In virtualized environment power consumption will typically be much less of legacy DC systems and with an improvement of the global DCiE (Data Centre Infrastructure Efficiency) index. Moreover with the significant reduction of physical devices (both servers and network devices), the reduction of power consumption is possible in two ways:

- Directly, reducing the amount of physical servers
- Indirectly, eliminating a portion of the power consumed by the power and cooling systems.

2.1.2. Increase the performance of offered services

The performance and quality of services can be improved in many different ways, depending on the definition of "performance" and "quality of service". Broadly speaking, the envisaged innovations could:

- Decrease the energy consumption per service delivered
- Deliver more services per unit of energy consumed
- Indirectly improve the service availability and reliability by allowing seamless switching to other servers/Data Centres in case of failures

Factors that influence the overall energy consumption of a DC are, for instance, the global System performance (Hardware & software architecture, Resource management & middleware, evaluation/modelling methodologies), the power and thermal issues (Power and thermal modelling, Power constrained performance) and the performance of the DC applications (Cloud computing, Content distribution, Hadoop applications, Real-time analytics).

From the availability and reliability point of view, some important elements that can be identified are the Communications Performance (Intra/Inter DC communication, Open-flow based networks, DC network architecture & protocols), the Storage and I/O Performance (Storage architecture, I/O scalability and performance) and the Security and Robustness (Performance of security solutions, Intrusion & misconfiguration monitoring, Variability and reliability modelling).

2.1.3. Increase customer satisfaction

The Customer satisfaction is one of the main metric used to build Data Centre business plan. Some main aspects that can potentially influence and increase customer satisfaction can be identified in:

- Increase value-for-money for the end customer, by reducing the overall operating costs for the DC operators, thus allowing more competitive pricing
- Increase service availability and reliability (see also 2.1.6)

- Propose "green" services to the end customers that are concerned with sustainability and environmental issues, so that the processing can take place on servers/Data Centres powered only by renewable sources (see also 2.1.5)
- By maintaining high level of customer satisfaction in relation to the offered services, the Data Centre can consolidated the pool of loyal customers and expand its footprint thus achieving higher revenues.

2.1.4. Improve the overall efficiency of the energy system

The "energy system" at large guarantees the delivery of the required power to the end user. It comprises of three main blocks: power generation, distribution and consumption. Within the scope of the present project, we are mainly concerned with the electricity system, because Data Centres mainly consume electrical power.

The electrical power system is a complex set of interconnected generation plants, transformers, distribution lines and other components that must guarantee in real time a perfect balance between the offer and the demand of electrical power. All the actors can in principle cooperate to improve the overall efficiency of the electric power system, and indeed one of the main innovations proposed by the "Smart Grid" paradigm is an architectural framework allowing precisely this cooperation. For example, the "demand response" mechanism is designed to allow the electrical power grid to influence the power demand at any given point in time, in order to "smooth out" the consumption "peaks" and make the overall energy system more efficient and less fragile. "Peak shaving", as it is called in the industry, is manly of concern of the electrical power utility, but if a "demand-response" scheme is in place, there are benefits also for the electricity consumers.

Data Centres Operators, being large consumers of electricity, can benefit from such schemes in various ways:

- Obtaining a better tariff form the local Utility by accepting to reduce power consumption at peak times
- Negotiating lower average energy costs by participating in "demand-response" schemes
- Potentially benefitting from national or European incentives by cooperating to the overall efficiency of the national energy system

2.1.5. Stimulate the adoption of green energy [10]

When Data Centres become integrated with the Smart Grid, they acquire a unique opportunity to potentially "shift" or "migrate" load in a different time or in a different location to exploit energy availability:

- **Shift processing power**: The ability to schedule some kind of time-independent workload to a different time period in the same day or even a different day. In this way, it is possible for both DC federations and single DC to exploit the renewable energy availability. For example if a utility has a higher percentage of variable generation resources, such as wind, there are times when there is excess generation due to higher wind speed. Some workload could be shifted in that time interval with a DR program. The DC Operator could therefore gain better tariffs from the utility if it joins in those programs.
- **Migrate processing power**: The ability to seamlessly move workload and, as a consequence, electricity load between servers in the same DC or Data Centres in different grid, utility, or region, or even different country. This can be exploited to allow the end customer to choose his/her preferred energy source. For example, the end customer may want his/her service to be powered

only (or mainly) by renewable energy sources. Due to the well-known intermittency of renewable sources, this can be better fulfilled by a federation of interconnected Data Centres than by a single, stand-alone DC. The DC Operator could therefore offer a new package deal to the end customers, comprising different options related to the mix of energy sources used to provide its services.

Another advantage in using green energy is the need to improve corporate image by going "green". There are official certificates that could make more attractive a “green” DC operator to those customers that are involved in environmental safeguard.

Old Data Centres had the need to build and maintain expensive and complex grid-level energy storage systems. A rational alternative is to use energy at locations with excess renewable generation by migrating computational jobs from a geographically distant Data Centre to the other. In this way it is possible to reduce or avoid the building and maintaining of energy storage systems.

Considering these advantages, load migration strategy with the required automation can be an excellent strategy for distributed and networked Data Centres.

2.1.6. Increase the availability and the reliability of DC federation

The availability of a network of federated Data Centres, along with a control logic able to seamlessly switch the processing load between servers of the same DC and between different Data Centres belonging to the federation, makes it possible to reduce the redundancy necessary to guarantee a high level of availability and reliability (e.g. mirror Data Centres for disaster recovery), and increase at the same time the backup options available to Data Centres Operator. The overall result is to increase the service availability and reliability, while reducing the infrastructural costs.

2.2. Technology Enablers

In general we identify the following DC technology Enablers:

2.2.1. DC Energy Consumption Optimisation

Servers’ utilization and their energy consumption in a DC is considered an important problem in the current times. Much of the server capacity remains unutilized during normal operation. Interaction-oriented servers do not always run at their peak processing capacity, since their workloads vary a lot, depending on time of day, day of the week or other external factors. They have significant buffer processing capacity to maintain performance goals, in case of unexpected workload increases. Interaction servers that run at peak throughput can impact the latency of individual requests and, consequently, can fail to meet SLA goals for response time. On the other hand, batch-servers often have less stringent latency requirements and run at peak throughput in bursts. However, their more relaxed latency requirements mean that sometimes running a large job overnight is sufficient. Both interaction and batch servers have idleness that can be exploited to reduce the energy used.

To this respect, there have been studies on a number of mechanisms and strategies that cater for better utilisation of energy within servers. The following paragraphs provide a brief introduction of such mechanisms, which can enable more efficient energy utilisation in a DC.

A number of energy-aware strategies for Data Centres have being proposed including workload consolidation [14] [15] , optimal placement of workload [16] [17] , scheduling of applications[18] [19] , detection of more power efficient servers, and reduction of power consumption by cooling systems [20] [21] .

Most of the energy-aware approaches and resource management algorithms for Data Centres consider only specific research problems and integrate only typical constraints, without considering some important factors, like:

- Data Centres have complex and quickly changing configurations;
- Data Centres are not homogeneous in performance, management capabilities and energy efficiency;
- Data Centres must comply with a number of users' and operators' requirements.

At the networking level, energy efficiency strategies span across all layers of the protocol stack [22] , often focusing on a particular layer only. Consequently, the system-level impact and the real hardware constraints are usually overlooked (an exception is [23]).

We elaborate below representative approaches towards energy efficient Data Centres, namely the Dynamic Voltage Frequency Scaling, the Dynamic Power Management and the Advanced Configuration and Power Interface.

2.2.1.1. *Dynamic Voltage Frequency Scaling (DVFS)*

Dynamic Voltage Frequency Scaling (DVFS) relies on the fact that power consumed by a microprocessor is a quadratic function of its operating voltage. Thus, reducing the operating voltage and consequently the operating frequency, provides substantial (quadratically) savings in power, at the cost of (linearly) slower code execution. The ability to dynamically adjust the processor frequency and voltage is a critical factor in DVFS. Instead of running at full speed and having idle parts of the time, the CPU should dynamically change its frequency to accommodate the current load and eliminate slack. To select the proper CPU frequency and voltage, the system must predict future CPU usage. Much of the recent work in DVFS has sought to develop prediction heuristics, but further research on predicting processor usage for server workloads is needed.

Utilising the scaling granularity, the work on DVFS may be divided into two categories, as inter-task and intra-task voltage scheduling. The former determines the supply voltage on a task-by-task basis, providing a more coarse-grained scheduling approach. The latter adjusts the supply voltage within the boundaries of individual tasks, achieving a more fine-grained scheduling. There are many scheduling policies, as those discussed in [24] [25] [26] [27] [28] , for hard real-time applications that are classified as inter-task. In such cases, the scheduling is performed at the task level by the OS, so as to reduce energy consumption, while meeting the hard timing constraints of each task. Additionally, there are a number of studies that implement intra-task DVFS, as part of compile-time optimization or by modifying the application code itself. In [29] , an intra-task voltage scheduling technique was proposed, in which the application code is divided into many segments and the worst-case execution time of each segment (which is obtained from a static timing analysis) is used to determine a suitable voltage for the next segment. In [30] a method based on a software feedback loop was proposed. In this method, a deadline for each time slot is provided.

Furthermore, the work in [31] and [32] proposed compiler-assisted DVFS techniques, in which frequency is lowered in memory-bound region of a program, with little performance degradation. DVFS approaches that rely on micro-architecture or embedded hardware, without any assistance from a compiler or a simulator have also been reported. In [33] a micro-architecture driven DVFS technique was proposed, where cache miss drives the voltage scaling. In [34] instruction per cycle (IPC) rate of a program execution was used to guide the voltage scaling. The work in [35] presented a policy to choose the optimal CPU clock frequency, under a fixed performance degradation constraint (of say 10%) based on dynamic program behaviour, such as the number of executed instructions and memory access counts during the whole execution time by using a performance monitoring unit (PMU). In [36] , a DVFS technique, which enables more precise energy-performance trade-off using PMU was presented, in which the optimal CPU clock frequency and the corresponding minimum voltage level are chosen based on the ratio of the on-chip computation time to the off-chip access time.

As we are moving towards an online approach to DVFS, which considers runtime information directly from the processor to infer the characteristics of the application dynamically, we come across two approaches regarding the level of formalism: purely heuristic-based and formal analytic schemes. The former, typically includes a set of manually selected rules and threshold values. At run time, certain processor metrics, such as cache miss rate [37] or queue occupancy [38] [39] are monitored. These metrics are then compared to the threshold values and one of the rules is applied depending on the result of the comparison. The heuristic approach has some significant limitations. First, for a result obtained from a given set of rules and parameters, it is not analytically clear how to further improve it and, thus, make the DVFS more effective. Second, the trial-and-error tuning process for parameters is very time consuming. Third, it is generally hard to scale the heuristics for a large system, as the number of rules and the tuning effort required can grow exponentially.

2.2.1.2. *Dynamic Power Management (DPM)*

Dynamic power management (DPM) is a design methodology that dynamically reconfigures an electronic system to provide the requested services and performance levels with a minimum number of active components. The fundamental characteristic of DPM is the availability of multiple modes of operation with varying performance and power characteristics. We can achieve a better power budget by dynamically switching between those modes, while maintaining a balanced performance and workload. However, transitions between modes of operation incur some cost, in terms of delay or performance loss. If a transition is not instantaneous and the component/chip is not operational during a transition, then performance is lost. In some cases the transition cost may be negligible, but, generally, it is not. In general, low-power states have lower performance and larger transition latency than states with higher power. This holds true for many single-chip components, like processors [40] and memories [41] , as well as for devices, such as disk drives [42] , wireless network interfaces [43] , displays [42] , which are more heterogeneous and complex than a single chip.

In [44] the authors have defined a DPM-based architecture, called PowerNap, which utilizes sleep states of various components of a server system and decides when and for how long each component should be put to sleep. In the PowerNap concept each time the server exhausts all pending work, it transitions to the nap state. In this state, nearly all system components enter sleep modes. While in the sleep state, power consumption is low, but no processing can occur. When new work arrives, the system wakes and transitions back to the active state. When the work is complete, the system returns to the sleep state. PowerNap concentrated on optimizing energy efficiency, while napping and minimizing transition time into and out of the low-power nap state. DPM involves mainly two types of techniques, predictive and stochastic. The former is based on the correlation between the past history and the near future system behaviour. Predictive techniques can be further split into static and adaptive. Static techniques utilize some threshold of a real-time execution parameter to make predictions of idle periods. The simplest policy is called fixed timeout, where after a predefined time-interval of inactivity, the system transitions to a low-power state. The major disadvantage is that an adjustment of the threshold value is required for each workload, leading to a performance loss on the activation. Additionally, the energy consumed from the beginning of an idle period till the timeout is wasted. To overcome the drawbacks of the fixed timeout policy, predictive shutdown and predictive wakeup have been proposed, based on the analysis of historical information. Static techniques are inefficient in cases the workload is unknown or vary over time. To address this, adaptive predictive techniques have been proposed. The basic idea is to dynamically adjust the parameters, which are fixed for the static techniques, according to the prediction quality of the past. For example, the timeout value can be increased if for the last several intervals the value led to over-predictions. Another way to provide the adaptation is to maintain a list of possible values of the parameter of interest and assign weights to the values according to their past efficiency. The actual value is the weighted average of all the values in the list.

Another way to deal with non-deterministic system behaviour is to formulate the problem as a stochastic optimization, which requires building an appropriate probabilistic model. In this case, system requests and power state transitions are represented as stochastic processes and can be modelled as Markov processes. At any moment, a request arrives with some probability and a device power state transition occurs with another probability, obtained by solving the stochastic optimization problem. The results obtained using the stochastic approach, are expected values and there is no guarantee that the solution will be optimal for a particular case. Moreover, constructing a stochastic model may not be straightforward in practice.

2.2.1.3. *Advanced Configuration and Power Interface (ACPI)*

Advanced Configuration and Power Interface (ACPI) specification [45] is an open standard defining a unified, OS-centric, device configuration and power management interface. It is important to note that ACPI does not put any constraints on particular power management policies, but provides an interface that can be used by software developers to leverage flexibility in adjustment of the system's power states. ACPI defines a number of power management states that can be applied in the system at run-time. The important states are:

- **Global System state (G-state)**. The Global state are: G0 (working), G1 (sleeping), G2 (soft-off) and G3 (mechanical-off).
- **Processor Power state (C-state)**. In G0-state, the CPU has several sub-states, (C0 to C3) that denote the operating, halt, stop-clock and sleep state, respectively. The deeper the C-state, the more power savings can be achieved and the longer latency the system will observe.
- **Processor Performance state (P-state)**. In C0, there are several sub-CPU performance states, P-States, where the CPU is operating under a variety of voltage and frequency settings.
- **Processor Throttling state (T-state)**. T-state is also a sub-state of C0. It saves power by only changing CPU frequency. T-state is usually used to handle thermal events.
- **Sleeping state.** G1 state is divided into several sub-states, S1 to S4. They differ with each other in power saving, context preservation and sleep/wakeup latency.

2.2.2. Energy Aware Virtualization

Usually, energy is not taken into consideration when speaking of virtualization in Data Centres, or if considered, it is limited to server energy consumption. However, for a virtualization model to realistically reflect energy efficiency many other factors should be considered.

Cooling and other support elements have a relevant effect in the global energy consumption of a DC. The type of energy used is another key factor to include in the optimization process, so that Data Centres that use green energies are favoured over those using fossil energies.

Therefore there are many different elements to be considered when building a model for energy aware virtualization.

To that end, information from all factors and resources involved should be collected at regular time intervals. Information regarding servers, storage and network resources in terms of performance, usage, availability and consumption are essential, but other important factors should be included as well. As shows in Figure 2-2 there are infrastructure resources in Data Centres, such as cooling and power resources that have a decisive contribution to energy consumption and efficiency, so that regular measurements must be collected as well. Other parameters to consider are those related to the type of energy sources of a Data Centre, favouring Data Centres with green power capabilities.

Environment information plays an important role in decision making; Data Centres with green energy capabilities depend on weather conditions, such as wind, temperature, sun hours and time of the day and time zone. Adequately forecasting the near future environment conditions make it possible to determinate whether green energies could be available and to what extent in each DC. Also, cooling efficiency and, therefore, energy consumption can be improved depending on the weather conditions, which should be taken into account when several synergetic Data Centres are available in locations with different climatic conditions.

To complete the model, the Smart Grid Network should also be taken into consideration. The Smart Grid must be kept informed about the time-varying energy consumption of the Data Centre. Also, requests from the Smart Grid to a Data Centre regarding the energy consumption targets should be processed.

Reorganizing workload for optimal energy efficiency typically means the migration of Virtual Machines to other servers in order to shut down idle servers and prioritizing the use of the most efficient servers. Moving Virtual Machines to servers in the same room can have a deep impact in energy consumption reduction. More particularly, the consolidation of Virtual Machines on physical servers can either decrease the required resources from physical servers or even decrease the number of physical servers required for Virtual Machine deployment. In this manner, we can allow part of the cooling infrastructure to be switched off or to decrease its consumption to a minimum.

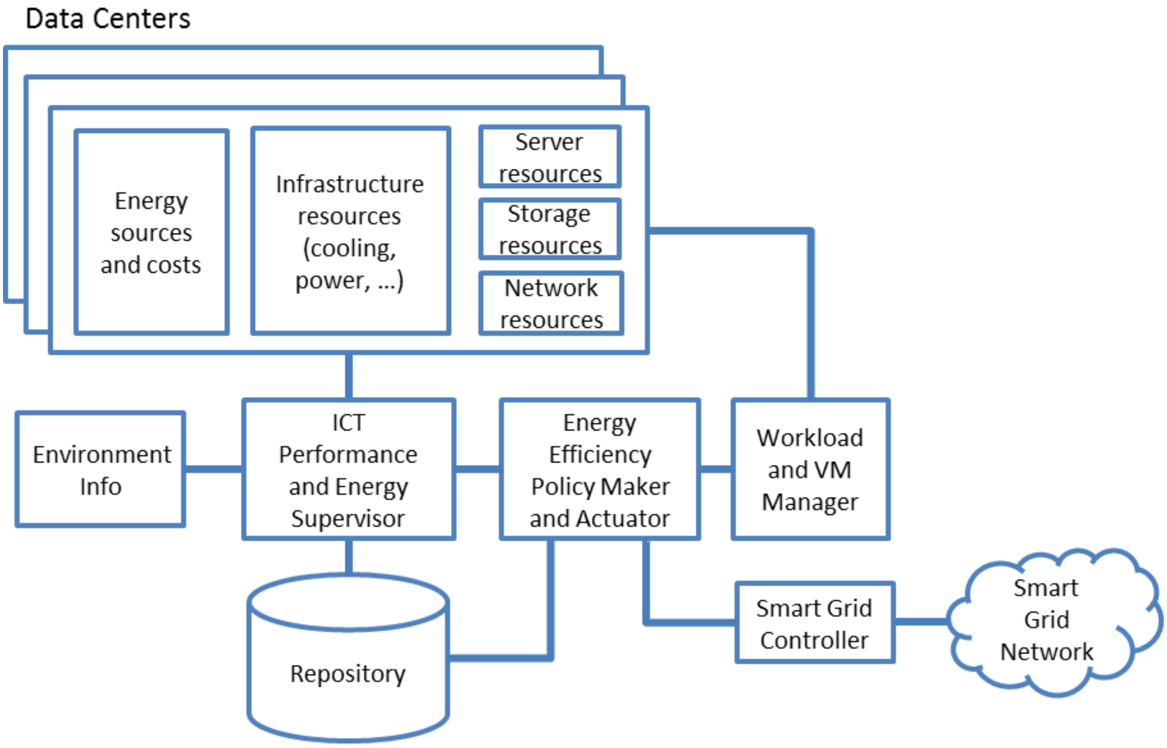

Figure 2-2: Data Centres high level architecture.

2.2.3. Demand/Response Power Consumption

Data Centres have significant potential for Demand Response (DR) opportunities. Different strategies can be applied, taking different operational characteristics and features into consideration. Some of these strategies focus on energy efficiency increment, whereas other incorporate service levels adjustments for demand response. DR strategies are normally focused either towards Site Infrastructure Optimization (considered as out of scope for this study) or towards IT infrastructure.

Data Centre IT infrastructure includes servers, storage and network devices, which typically account for less than 50% of total Data Centre energy use. Cooling systems (and other operational related energy consumption) are responsible for the other half of energy use. As a result any DR strategy for IT infrastructure load shall result in reduction of cooling load. Data Centre DR strategies generally fall into the categories of load-shedding (dropping load completely) and load-shifting (moving load from peak to off-peak periods).

DR Strategies for IT Infrastructure can be broken down as follows:

A. Virtualization technologies

Such technologies can be used to consolidate redundant servers automatically, on short notice. This strategy includes the shift of workload and the resources reallocation in cases of low to medium DC utilization. Thus provisioning and reconfiguration of virtual machines for DR events can be automated, taking into account times, workloads, and SLAs. Virtualization DR techniques may include (some of) the following:

- **Server consolidation**: automated adjustment of processor utilization rate by using virtualization technologies in response to a DR signal with consequential higher utilization rates for the processors, enabling the shutdown of the redundant servers. Very high utilization rate may increase energy consumption nonlinearly.
- **Storage consolidation**: use of virtualization technologies to increase server storage density in response to a DR signal, in order to shut down redundant storage. Very high storage density rate may marginally increase energy consumption or reduce expected storage lifetime.
- **Network virtualization**: use of Storage Area Networks (SANs) for short periods to allow virtualization of remote storage devices, which would improve local storage device efficiency, or shut down local storage devices for greater load reduction. Immature technique with unproven energy saving potential.

B. Shift or Queue Job Processing

Identification and management of job priorities and queues to defer IT processes and workloads from on-peak to off-peak periods during DR events, by using virtualization techniques, without violating SLAs. This strategy is to be used in non-mission-critical Data Centres to shift server processes to non-peak time and to consolidate servers to temporarily reduce energy use and is applicable to non-mission-critical applications.

C. Built-in Equipment Power Management

Instead of shutting down of equipment due to virtualization or shifting IT and back-up processing, utilization of built-in power management features in a certain percentage of equipment in real time. Load could be shed based on increased efficiency resulting from lowered equipment workload.

D. Load Migration Technologies for Shed or Shift

Energy-saving technologies and strategies, such as synergetic DR for both IT and site infrastructure and temporary load migration to shed or shift Data Centre load. Data Centres with fully networked infrastructure within different electrical grids or geographic locations, may benefit from temporarily shifting loads to other locations in response to a DR event. This is a technique developed primarily for disaster recovery that requires advanced notification and coordination among DC operators as well as local utilities providers.

2.2.4. Energy-aware SLA Management [11]

Actual Service Level Agreement (SLA) normally defines:

- Parties and other legal issues
- Business rules, responsibilities
- Service description
- Quality of Service (QoS) and metrics to measure SLA violation
- Guarantees and Penalties

Usually, no environmental objectives like energy consumption is enclosed within traditional SLAs and the operational boundaries are defined by some fixed parameters:

- DC availability
- Security
- Network Latency
- System Performance

A more energy-aware SLA could lead to a more eco-efficient operation of the Data Centre, compared to traditional, performance-based SLAs.

However energy saving strategies have an impact on certain QoS parameters (typically the network latency and the system performance) defined in the SLAs. If the QoS levels must be relaxed by the DC operators to meet their energy constraints, this change must be notified, negotiated and accepted by the end customers.

The DC operators could publish different kind of SLA Templates (from traditional SLAs to fully energy-aware SLAs), so that the end customer is enabled to choose the one that best fits his needs; additionally the end customers could be given the opportunity to customize the proposed SLA depending on their specific needs. This leads to the adoption of SLAs that have a more dynamic nature and that can be modified and adapted, based on the business needs of the DC and the end-customers, as shown in Figure 2-3.

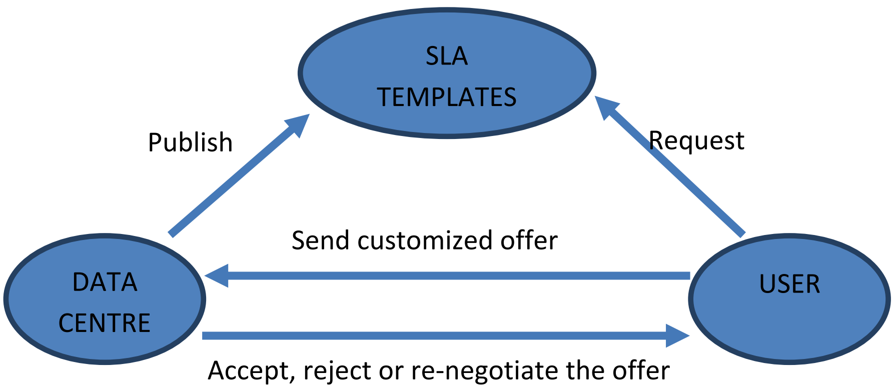

Figure 2-3: Dynamic SLA diagram.

This kind of SLAs could enable either a decrease of energy consumption or a better use of renewable energy sources. To enable this kind of scenario the DC metrics related to the energy consumption of services must be modified in order to give to the users a clear vision of the energy saving strategies or the use of renewable energy sources.

From the DC operator point of view the incentives are:

- Energy cost saving (ICT equipment + HVAC)
- Comply with environmental regulations (e.g. CO_2 certificates)
- Green marketing options

On the other side the end customer could benefit of:

- Reduced price of Data Centre offered services
- Green marketing options

Two different situations can be imagined:

In the first one the DC operator can propose to the end customer a variation of the traditional SLA that includes also economic discounts proportional to the actual degradation of QoS levels measured during a given time frame. In this case, there is a fixed formula, agreed by both parties (the DC operator and the end customer), that correlates the economic discount to the QoS degradation experienced by the end user. The SLA is still “static”, in the sense that both the economic discounts and the conditions under which they can be applied are fixed and cannot be changed or negotiated.

In the second and more complex one, the SLA could be more dynamic, and it could include a negotiation scheme. In this case the DC operator can dynamically propose to the end customer a variation of the QoS levels and a corresponding economic incentive, based on the actual state of the power grid. The customer could accept the DC proposal, reject it, or send back a counter-proposal with different parameters depending on his needs. This negotiation should end in a fixed period of time, compatible with the smart grid dynamics. In this case, the SLA is more “dynamic”, in the sense that the scheme of the negotiation remains fixed, but the outcome of such negotiation can vary depending on the actual situation. Obviously, such a scheme assumes that there is a smart energy management system in place at DC site, and that the end customer has an advanced information system able to automatically negotiate the QoS with the DC.

2.3. The synergetic approach used by DOLFIN

Today, most Data Centres are part of computing and storage clouds, offering their customers a virtual operating environment, exploiting the advancements of virtualisation technology. In this context, DOLFIN brings the notion of a cooperating network of Data Centres, called Synergetic Data Centres, so as to enable seamless and autonomic movement of Virtual Machines (Virtual Machines) across energy-conscious Data Centres.

The dynamic reallocation of ICT workload within Synergetic Data Centres requires the presence of a controlling entity that can coordinate relevant actions. That entity, from an architectural point of view, can be either centralized or distributed. This highly depends on the business model that will be adopted to support the network of cooperating Data Centres. If the Synergetic Data Centres are under the same administrative authority, then it would be reasonable to assume that a centralized control would be adequate to address the needs of the individual Data Centres. In such a scenario the centralized control point would guarantee that the needs of a single provider would be addressed at any time.

Alternatively, if the Synergetic Data Centres are under the control of different administrative authorities, then, in order to become part of the cooperating network of Data Centres, it would require - from the business point of view - to establish specific SLAs that dictate their cooperation (for instance, how many resources can be made available to other Data Centres and under which conditions). In this case, there would be no centralized entity responsible for the overall control of the Synergetic Data Centres. Instead, each DC would be responsible for controlling its own resources and share them with other Data Centres in a dynamic manner. In this scenario, the control of the Synergetic Data Centres is more distributed. Of course, there can be evolution scenarios, where, an initial centralized control would be succeeded by a more distributed control, as the need for co-operation between Data Centres that belong to different administrative authorities increases.

It is of primary importance that the migration of ICT workload between Synergetic Data Centres is taking place in a manner that will not disrupt the provisioning of ICT services. In order to do so, such a migration process would require providing:

- **Migration of the operating infrastructure**. The operating infrastructure of the ICT service will need to become available in the new DC. This includes the hosting server and the operating system, in the form of a VM, application or service software, storage area and access to networking resources. This part of the migration process mainly involves setting up and reserving processing, storage and networking resources in the new DC, so as to create an operational environment that is identical to the one where the ICT service/application is already running. To create such an environment there is no need to wait until the decision for migration is taken. It can be arranged and done well in advance. To this respect, the Synergetic Data Centres may maintain a list of ICT services/applications that can be migrated from other Data Centres. Given such a list and knowing the operating requirements of the ICT services it would be straight forward to prepare an operating environment, before the migration is requested. Such a list could be static, in which case its maintenance would be done in an offline mode. Alternatively, the list could also be dynamic, in which case it would be possible to modify it in an online mode. The second option requires the establishment of a framework between Synergetic Data Centres that would allow them to commonly agree on such a list.
- **Migration of ICT service data**. The amount of data that need to be migrated might differ, depending on the particular ICT application/service. However, in the general case, it is expected that the volume of migrated data can be large and, thus, it could significantly increase the time required to complete the online migration process. The data to be migrated could be divided in two categories. The first one involves the data that reside in the main memory of the hosting server. This is actually the currently active operating data-set and portions of that data might be under modification, when the migration process starts. The second category, which usually concerns the biggest volume, involves the service-related data that are found in some storage area, in the form of files or data bases. Considering the data migration process the following approaches could be utilized or combined together:
    - **Push**. In this case, the source Virtual Machine continues running, while certain parts of the service data are pushed across the network to the new destination. To ensure consistency, those parts that are modified during this process, are eventually re-sent.
    - **Stop-and-copy**. In this case the source Virtual Machine is stopped, data are copied across to the destination Virtual Machine and then the new Virtual Machines started.
    - **Pull**, where the new Virtual Machine executes and, if it accesses some data that have still not yet been copied, a fault is generated and data are “pulled” across the network from the source VM.
- **Traffic redirection**. All the traffic, both incoming and outgoing, that belongs to the migrated ICT service/application, will have to be redirected towards the new DC. This would require a reconfiguration of the networking devices between the two Data Centres. Those modifications

might range from ARP cache changes or DNS modification or even setting up a general forwarding mechanism at the source DC.

Moving Virtual Machines between Synergetic Data Centres is not a trivial problem, as very strict Service Level Agreements (SLAs) to the DC's clients should be guaranteed. However, in many cases, a high performance SLA, which involves many ICT resources, high cost and high energy consumption to sustain it, does not correspond to the expected, equally high workload. For instance, if the offered ICT workload is, on the average, much lower than the maximum workload anticipated in the SLA, then a large portion of the energy consumed is actually wasted, without producing any useful service results. If the DC and the respective client can agree in lowering the SLA expectations, then energy will be saved and the client will be charged less. This immediately brings into the game the option of SLA renegotiation, which would adjust the SLA requirements with specific customers, so as to achieve energy savings. In this respect, the Data Centre will automatically select a number of customers, with high performance SLA requirements and low average workloads, and initiate the SLA renegotiation process. This will end up with a number of the selected customers agreeing to decrease their SLA requirements, in exchange for decreased service cost.

3. DC Business Models

With the proposed technical approach of DOLFIN it is possible to realise energy savings that can actually be translated to cost saving for the Data Centre customers. This is definitely a new business opportunity for Data Centre operators, so as to attract new clients and re-enforce the relationships with the existing ones.

Assuming that a business model is the plan implemented by a company to generate revenue and make a profit from operations, in this section we will focus on making a brief study of the existing business models for Data Centres and how they can be affected (modified or adapted) by energy efficiency considerations or actions, so as to incorporate the DOLFIN approach. To this respect, we will discuss how the energy efficiency considerations could affect the existing business models of Data Centres, what changes could we expect, and in which direction.

We will also have a brief discussion regarding the main actors that we foresee in DOLFIN and which are able to drive the business needs of the DOLFIN system.

3.1. Actors

In a Business Scenario or in a Use Case, the role of an Actor is of primary importance, since it can trigger some functionality, receive the results of the processing done or influence which steps of a process will be followed, under certain conditions. To this respect, we have identified a number of Actors that can interact with the DOLFIN system and these include the following:

- ***Data Centre Operator – DCO:*** This entity is responsible for operating a DC or a group of Data Centres that are part of the same administrative domain. It is responsible for providing ICT services to customers, adhering to specific Service Level Agreements (SLA).

  The primary objective of a DCO is to offer ICT services under the promised SLA, maximising the utilisation of the ICT infrastructure, while maintaining the electricity consumption within levels that are proportional to the ICT processing work delivered. Furthermore, the DCO would like to take advantage of any demand-response curtailment incentives that would be available, so as to decrease its operational cost and provide greener ICT services. In order to benefit from the incentives, DCO might be required to take immediate actions or even schedule them for the near future.

- ***Aggregator:*** This entity acts as a service provider by enlisting electricity consumers to participate in demand-response curtailment programs and sell the combined load reduction to electricity retailers or Distribution System Operators (DSO). Typically, the Aggregator takes a percentage of the demand-response incentive as compensation, passing the rest on to the consumer. To this respect, the Aggregator could represent a number of different entities, such as Utility Operators, DSOs, Distributed Energy Resources (DER) or Grid Operators, in an effort to avoid electricity consumption peaks by offering demand-response programs to DCOs. In the simplest scenario, the role of the Aggregator could also be played directly by the entities that it represents.

The objective of the Aggregator is to maintain a balanced electricity supply and demand within the energy grid network that is under its immediate responsibility, by offering incentives to DCOs, so as to lower their electricity demands.

- ***Customer:*** This entity consumes ICT services offered by the DCO. Usually, this entity utilises the ICT services so as to store, retrieve, process and transfer business information under a specific contract and SLA guarantees provided by the DCO.

  The objective of a Customer is to receive ICT services with a guaranteed SLA that correspond to a reasonable and fair price, or even favourable, in case such an opportunity could arise. A Customer may also opt to participate in a demand-response curtailment program and receive some cost benefits and contribute to the implementation of policies opting for green-powered ICT services and Data Centres.

- ***Authorities:*** This Actor represents any entity that, from a regulatory or policy perspective, is posing rules on the way that the DOLFIN system should operate or interact with any external system. In this context, environmental, energy, data security and processing related rules might be applicable.

  The objective of an Authority is to protect the public interest and to promote a healthy market competition. To this respect it can influence the framework of operation of DCOs, Aggregators and Customers, determining also the way they interact and exchange information.

- ***Utility Operator:*** This Actor provides electricity using fixed or multi-tariff pricing schemes. In case of multi-tariff, the cost per electricity unit could vary depending on the day of the week, the time of day, certain electricity consumption limits or, possible, other parameters.

  The objective of this Actor is to provide electricity to consumers, maintaining stability between demand and supply.

3.2. Existing business models for Data Centres

Taken into account that each Company operating its own Data Centre has developed a business model tailored to the company vision and goals, some common features can be identified as key elements to describe a typical business model for Data Centre. A business model can be understood by breaking it into elements. Following the division made in [8] , a certain number of key elements are isolated with the basic idea is that the business model is created by organizing these elements. The key elements are Value proposition, Customer segments, Key activities, Key resources, Key partners, Cost structure and Revenue streams.

Customers constitute the heart of any business model. Without (profitable) customers, no company can survive for long. In order to better satisfy customers, a company may group them into distinct segments with common needs, common behaviours, or other attributes and tailor offered service to the chosen segment. Typically the Data Centre Customer can be grouped in two different segments: business users and normal users. ***Business users*** are companies that purchase IT services in the form of PaaS (Platform as a Service) or IaaS (Infrastructure as a Service) framework [49] to create an add value in the form of specialized service to be offered in turn to their customers. Typical example of an Application Provider who do not to build its own infrastructure and buys Computing capacity and Storage services from a Data Centre Owner, and leverage on the purchased resources to create its own added-value services (e-commerce service for example) that will be sold to its end-users. The second segment type is identified with ***normal user,*** who buys Data Centre services mainly for amusement and not with specific business goals.

The **Value Propositions** Building Block describes the bundle of products and services that create value for a specific Customer Segment. The value proposition can be identified with the Service portfolio offered by the Data Centre. The typical Data Centre services can be identified in the following:

Computing Services leverage the IaaS paradigm, where end-user is offered a certain bundle of virtual resources in terms of virtualized hardware and storage. In a state-of-the-art Data Centre the process thorough a service is instantiated is totally automated. End-user can access its own created resources via a web based interface.

Connectivity Service, where the end-user uses the Data Centre connectivity infrastructure as if the latter was an Internet Service Provider (ISP). In certain cases, for example when the Data Centre is owned and managed by an ISP, Data Centre can also deliver connectivity service acting as a PoP (Point Of Presence) and aggregating customer traffic to be inserted on the provider Backbone.

Co-location service is a service type where the customer purchases physical space within the Data Centre to host their own equipment. Typical case of a Content Delivery Network provider (CDN), who needs to enlarge its geographical presence by deploying network devices in strategic point to gain visibility over the wide area network.

Hosting service (sometimes referred as Web Hosting service) is a type of Internet hosting service that allows individuals and organizations to make their website accessible via the World Wide Web. End user web sites are physically hosted within Data Centre infrastructure and made available to the public internet community.

Apart from the above mentioned primary services, Data Centre can offer additional services that can be considered as add-on to the previous ones, like Disaster-Recovery service (resources are replicated in geographical diversity to allow for service continuity in case of disasters), Security services (Deep packet inspection, Connectivity over VPN, strong authentication). All these different type of services, made available with different granularities and performance characteristics compose the portfolio of the Data Centre, which must be strategically linked to the customer segment and to the business goals to be achieved.

Despite the portfolio service diversity, whenever a service is offered to the end-user it must be linked to proper **SLA (Service Level Agreement**). An SLA is a formal definition of the relationship that exists between a service provider and its customer. An SLA is used to specify what the customer should expect from the provider, the performance, availability and security objectives of the provided ICT service, as well as the procedures to be followed to ensure compliance with the SLA.

As for other managed network services, the typical SLAs between a cloud service provider and its customers should encompass at least the minimum and maximum service levels across all tiers of service provisioning. This should regulate:

- Planned and unplanned downtime,
- The process in which the DC provider will notify the company of planned downtime, and mechanisms to accept or defer,
- Contractual penalties for any unplanned downtime suffered outside of the agreed SLA,
- Agreements for events, which the DC provider has no control over; for example, natural disasters at the provider's Data Centre,
- Operational Level Agreements (OLAs), which record engagement details between the DC provider support teams including contact details during business and non-business hours.

The **Revenue Streams** element represents the cash a company generates from each Customer segment. If customers comprise the heart of a business model, Revenue Streams are its arteries. Revenue stream is strictly based on Monitoring activities, performed over purchased services, and on billing activities.

Different models can be foreseen starting from fixed/dynamic pricing models to pay-as-you-go model, monthly/weekly subscription.

Key resources and Key activities are the strategic assets and the activities to transform those assets in the value proposition to be offered to the end-users. From the Data Centre point of view the key resources are represented by the IT infrastructure that will be used to build the IT services for the customers. On the other hand key activities are the operations of specialized IT personnel to provision, configure and maintain the IT services to be delivered to the end user.

The different mix of key elements described above can potentially lead the Data Centre owner to arrange the infrastructure and to strategically position the Data Centre activity in a certain number of different combinations. The most important of them are outlined below:

- colocation (retail) providers
- wholesale providers
- managed/dedicated hosting
- cloud services

Retail colocation providers sell down to the individual racks or cages, with cages ranging anywhere from 50 to 500 square meters. Retail customers are traditionally small and medium-sized businesses (SMBs), and they are charged a fee per rack or on the basis of energy usage, although larger enterprises are beginning to leverage this model for up-scaling and down-scaling situations (for example, accounting firms during tax season). Retail colocation providers also sell to shared, dedicated and managed hosting providers. In an effort to differentiate themselves, retailers are focusing on expanding their business by offering new services, such as application management. This also drives profitable growth.

Wholesale providers build larger facilities ranging from 1,000 to 2,000 square meters. They provide the power and cooling shell of the Data Centre for purchase or lease, typically by a single user or small number of users. The facility is typically built in increments, or “pods,” of at least one megawatt. Wholesale providers have fewer customers than retail colocation providers, but they operate under longer-term contracts. Customers tend to be Fortune 2000 enterprises, retail colocation companies and/or managed hosting companies. The wholesale model is much more focused on growth through expanding the footprint in terms of the number and square footage of Data Centres.

With **dedicated hosting**, a customer leases a single server with basic services; conversely, with shared hosting, multiple customers will share a single server. Managed hosting providers offer customers comprehensive systems management, database administration and sometimes application management. The managed service model provides a high level of flexibility for clients.

Cloud providers offer on-demand capabilities and the most flexible solution for storage, networking and/or server capabilities. The cloud model comes in multiple forms, including infrastructure as a service (IaaS), platform as a service (PaaS) and software as a service (SaaS). These models offer a pay-per-use method and are very attractive to SMBs, small and medium-size enterprises (SMEs), and enterprise customers.

3.3. Energy efficiency affecting DC business models

In the previous section we have described the key elements that compose the costs for operating the Data Centres, we have described the actual business models of state-of-the-art Data Centres, we have identified the main actors within DOLFIN project framework and finally we have outlined the main technology enablers to gain an achievement in the energy efficiency. In the remaining of this section we will try to clarify how the DOLFIN project innovation is not only related to a technical shift in Data Centre infrastructure, but will have deep impact on business models and strategic management, too. The key elements of how DOLFIN affects the DC business models are grouped in areas and analysed in the paragraphs below.

3.3.1. Partnership with other Data Centre

This is a very hot topic in the scientific community, e.g. the idea of Data Centres under different administrative domains that team up for technical reasons (e.g. sharing resources, optimizing inter-Data Centre traffic, achieve energy efficiency) and business reasons (e.g. geographical positioning, enlarge the footprint). This approach is often referred to as Cloud Federation, or Cloud to Cloud interoperability or Inter-cloud [9] , where the term cloud must be understood in the sense of Cloud computing, as a new design pattern for large, distributed Data Centres. To realize this new paradigm, a certain number of issues must be taken into consideration:

1. Federation discovery, formation, security and technical issues (protocols, standardization)
2. Management of the inter-cloud traffic generated
3. Business relationships among different Data Centres should be formed
4. SLA mapping, in case of service mobility

3.3.2. SLA dynamic negotiation with end-user

This will have a substantial impact on Data Centre business and strategies, since it foresees a critical shift on the state-of-the-art SLA to be offered to the end-user. The following areas are forecasted to be impacted:

1. SLA modification, passing from a static form to a more dynamic SLA
2. Performance measurements that should take into account the new dynamic behaviour of SLA and related changes on Data Centre billing service
3. Service granularities and potentially customer segment
4. Incentives for end-user to be outlined

3.3.3. Smart grid interactions

The modernization of the electric power grid is central to international efforts to increase reliability and energy efficiency, transition to renewable sources of energy, reduce greenhouse gas emissions, and build a sustainable economy that ensures prosperity for future generations. Globally, billions of dollars are spent to build elements of what ultimately will be “smart” electric power grids.

The notion of an advanced power grid for the 21st century is based on adding and integrating many varieties of digital computing and communication technologies and services with the power-delivery infrastructure. Bidirectional flows of energy and two-way communication and control capabilities will enable an array of new functionalities and application.

Distinguishing characteristics of the Smart Grid include:

1. Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid;
2. Dynamic optimization of grid operations and resources;
3. Deployment and integration of distributed resources and generation, including renewable resources;

4. Development and incorporation of demand response, demand-side resources, and energy-efficiency resources;
5. Deployment of ‘‘smart’’ technologies for metering, communications concerning grid operations and status, and distribution automation;
6. Integration of ‘‘smart’’ appliances and consumer devices;
7. Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal-storage air conditioning;
8. Provision to consumers of timely information and control options;
9. Development of standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid.

The applications of advanced digital technologies (i.e., microprocessor-based measurement and control, communications, computing, and information systems) are expected to greatly improve the reliability, security, interoperability, and efficiency of the electric grid, while reducing environmental impacts and promoting economic growth.

This global evolutionary path for the electric energy system will have profound impacts on the final energy consumers. In particular, most of these impacts can be modelled by the so called Demand Response (DR) paradigm. DR is a mechanism to influence the final consumption of electricity in response to supply conditions, for example, having electricity customers reduce their consumption at critical times or in response to market prices.

The obvious pre-conditions of any DR scheme is that there must be a “smart” electric grid in place, able to send requests to the final energy users, and there must be “smart” energy consumers able to dynamically adapt to the power grid’s requests. There can be many ways to implement DR schemes. One of the most popular is to actively engage customers in modifying their consumption in response to pricing signals. But this is by no means the only one. We can imagine for example flexible, energy-aware contracts between electrical utilities and their customers, as well as sophisticated, feedback-loop control schemes between the power grid and the energy users.

A DR energy system is an efficient and effective method for reducing overall energy use and cutting peak load, thus positively impacting the European objectives to increase sustainability as well as a reliable and cost efficient energy supply.

More specifically, DR impacts a broad variety of the challenges faced by the electricity industry, including:

- Contribution to the CO2 emissions reduction target
- Contribution to additional integration of renewable generation to the grid
- Cuts in the overall annual consumption of electricity
- Financial savings for consumers and the economy
- Lowered need to invest in peak capacity and therefore a lowered need to construct new power plants

In the long term DR can aid utilities to change their business model from a volume centred model to a more tailored, customer centred approach with increasing focus on value added services provided to specific customer segments. On the other hand, energy consumers can benefit in many ways from DR and new business scenarios can be thought of.

In the DOLFIN context, for example, there may be many business scenarios that can take advantage from DR schemes when they are in place. Most of them address the general business objective described in paragraph 2.1.6, i.e. "improve the overall efficiency of the energy system". Basically, all these scenarios are based on the ability of the DC energy management system to dynamically modify the power consumption of one or more Data Centres in response to stimuli and requests coming from the power grid. The benefits for the DC Operators may come from different sources: optimization of energy costs by exploiting dynamic pricing schemes (see for example the "Multi tariffs from the Utility companies" scenario in Chapter 4), energy-aware contracts with DC's customers (see the "SLA Renegotiation with end customers" scenario) and flexible contracts between the DC Owners and the "Smart Grid" (see the "Flexible contract between the Utility, the Smart Grid and the DC owner" scenario).

3.3.4. Impact on key operations

DOLFIN framework will have a deep impact in key operations area (deployment of DOLFIN solution, automation, maintenance) in terms of deployment of proper DOLFIN solution, automated mechanism for the management of new SLA, integration of new interfaces related to DOLFIN within the Cloud (or Synergetic) Management platform.

4. Business Scenarios

The envisaged business scenarios (BS) of DOLFIN could be classified in 3 main categories:

1. **Absolute energy reduction**: this class comprises the entire BS related to the reduction of the energy consumed by the Data Centres (equal services provided). This reduction can be achieved in different ways, but the end result is straightforward: less energy consumed means cost reduction, the possibility to benefit from energy-efficiency incentives, and other indirect advantages for the DC Operator.
2. **Power consumption manipulation to achieve the energy stabilisation**: in this case, the goal is not necessarily to reduce the absolute consumption of energy, but to distribute it better geographically and temporally, in order to achieve efficiency at a higher level, that of the entire energy system (see chapter 2.1.4). The benefits for the DC Operators in this situation usually derive from “demand-response” agreements with the electrical power utility.
3. **Improve the quality of the energy mix towards environmental “friendliness”**: this class includes all the BS that focus on choosing a given “energy mix” to power different services. This ability can be exploited to foster the use of renewable energy sources, e.g. by letting the final customer select a “green energy mix” to power his/her services. The benefits for the DC Operators can be: to provide new “green” offers to the market, to benefit from national or European incentives and to improve their brand reputation.

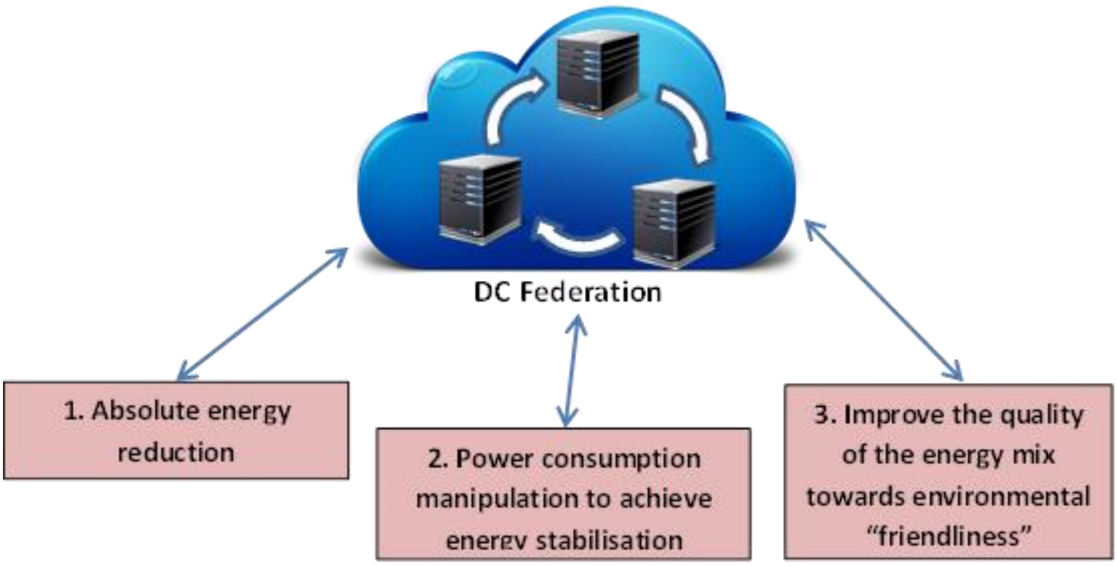

Figure 4-1: Business Scenarios main classes

4.1. Introduction

In order to describe the Business Scenarios we have decided to describe Dolfin business scenario via a template in order to allow for a coherent description based on a certain number of macro-aspects that are necessary for a complete description of the scenario. Those aspects are described in Table 4-1.

BS ID:	A globally unique identification of the Business Scenario		
BS Name:	A user-defined identification. Preferably a short active verb phrase describing the goal to be reached, the purpose of the Business Scenario		
Created By:	Initial Author	**Last Updated By:**	Last person who updated the table
Date Created:	Date of the table creation	**Last Revision Date:**	Date of last revision
Business Objectives:	The Business Objective(s) addressed by this Business Scenario: all the business objectives have been identified in Chapter 2.1		
Key Actors:	Specifies which (human and computer) actors are part of the Business Scenario (should be named in the list of actors)		
Value proposition:	The collection of services offered to meet the needs of customers.		
Customer Segment:	Various set of customers can be segmented based on the different needs and attributes: Mass Market, Niche Market, Segmented, Diversify, Multi-Sided Platform / Market.		
Revenue Stream:	The way a company makes income from each customer segment. Several ways to generate a revenue stream: Asset Sale, Usage Fee, Subscription Fees, Lending/Leasing/Renting, Licensing, Brokerage Fees, Advertising…		
Metrics:	The parameters through which the performance is measured		
Related use cases:	All the Use Cases that can be addressed to this scenario		
SLAs involved:	The different SLAs between the key actors		
Assumptions:	Particular preconditions that must be verified		

Table 4-1: Structure of Business Scenario.

4.2. Absolute energy reduction

This class comprises of all the BS related to the reduction of the energy consumed by the Data Centres (equal services provided). This reduction can be achieved in different ways, but the end result is straightforward: less energy consumed means cost reduction, the possibility to benefit from energy-efficiency incentives, and other indirect advantages for the DC Operator.

4.2.1. Energy efficient workload redistribution

BS ID:	BS.1.1		
BS Name:	Energy efficient workload redistribution		
Created By:	Fabio Pandini, Wind	**Last Updated By:**	Fabio Pandini, Wind
Date Created:	11.12.2013	**Last Revision Date:**	11.12.2013
Business Objectives:	• Improve the overall efficiency of the energy system • Reduce operational costs		
Key Actors:	• DCO • Customer		
Value proposition:	• Operational cost saving • SLA renegotiation option that distinguishes the DCO from competitors • SLAs with discount prices for Customer		
Customer Segment:	Customers that have explicitly accepted the option of having their SLAs renegotiated, when the need arises.		
Revenue Stream:	• Reduce the operational cost, with a potential decrease of service fees, having, however, a positive balance. • Benefits from energy efficiency certificates.		
Metrics:	• Energy saving • Operational cost saving • Customer service quality (customer satisfaction)		
Related use cases:	UC.1.1.1, UC.1.1.2, UC.1.1.3		
SLAs involved:	• DCO to Customer SLA • DCO to DCO SLA		
Assumptions:	A range of SLA options is foreseen at the contract level and is available to the project.		

Table 4-2: Energy efficient workload redistribution

4.3. Power consumption manipulation to achieve energy stabilisation

4.3.1. Multi tariffs from the Utility companies

BS ID:	BS.2.1		
BS Name:	Multi tariffs from the Utility companies		
Created By:	Fabio Pandini, Wind	**Last Updated By:**	Fabio Pandini, Wind
Date Created:	11.12.2013	**Last Revision Date:**	11.12.2013
Business Objectives:	• Reduce operational costs (related to energy consumption) • Improve the overall efficiency of the energy system		
Key Actors:	• DCO • Utility Operator • Authorities		
Value proposition:	• ***DC Operator:*** lower the operational cost related to energy consumption, by shifting ICT processing outside of the high-tariff energy window, to time periods with cheaper energy tariffs. • ***Utility Operator:*** high economic return in case the DC Operator decides to consume power during the high-tariff energy window. Alternatively, if ICT processing is shifted towards low-tariff energy windows, then it becomes easier for the Utility Operator to handle cases of peak power consumption.		
Customer Segment:	This Business Scenario does not address a specific customer segment of the DC, since the benefits are targeting only the DCO or the Utility Operator.		
Revenue Stream:	• Energy cost reduction • Increase the revenues by serving additional ICT workload, when electricity prices are low.		
Metrics:	• Operational cost saving • Tariffs		
Related use cases:	UC.2.1.1, UC.2.1.2, UC.2.1.3		
SLAs involved:	DCO to Utility Operator		
Assumptions:	• If the energy tariffs can change dynamically, a Smart grid should be in place and the DC operator should have an automatic control system to interact with the smart grid.		

Table 4-3: Multi tariffs from the Utility companies

4.3.2. Flexible contract between the Utility, the Smart Grid and the DC owner

BS ID:	BS.2.2		
BS Name:	Flexible contract between the Utility, the Smart Grid and the DC owner		
Created By:	Fabio Pandini, Wind	**Last Updated By:**	Fabio Pandini, Wind
Date Created:	11.12.2013	**Last Revision Date:**	11.12.2013
Business Objectives:	• Reduce operational costs • Improve the overall efficiency of the energy system • Increase the availability and reliability of DC federation		
Key Actors:	• DCO • Aggregator • Utility Operator		
Value proposition:	• DC Operator: economic benefits from the Aggregator if it is able to accept some power availability reduction or interruption in some dynamic time slots. • Aggregator/Utility: ability to handle power peak absorption and in general to reduce infrastructural costs.		
Customer Segment:	In this case the "customer" is actually the DC Operator		
Revenue Stream:	This BS acknowledges the fact that Data Centres have evolved into big electricity consumers and, because of that, may have special treatment by Utility Operators. To this respect, we foresee the establishment of flexible contracts between the Utility Operator and the DCO that would allow the latter to enjoy preferable energy prices, when the energy consumption is kept below certain limits. This BS explores the special and customized contract between the Utility Operator and the DSO, while, at the same time, it utilizes the Aggregator's services to materialize the DCO's privileges. In this manner, we expect to achieve the following benefits for the DCO: • Discounts from aggregator/utility or if the agreement is met by the DCO • Possible acquisition of energy efficiency certificates		
Metrics:	• Operational cost saving • QoS of the electric power grid		
Related use cases:	UC.2.2.1, UC.2.2.2, UC.2.2.3		
SLAs involved:	Utility to DCO SLA Aggregator to DCO SLA		
Assumptions:	• A Smart grid should be in place and the aggregator should be connected to it • The DC operator should have an automatic control system to interact with the smart grid		

Table 4-4: Flexible contract between the Utility, the Smart Grid and the DC owner

4.3.3. SLA Renegotiation with end customers

BS ID:	BS.2.3		
BS Name:	SLA Renegotiation with end customers		
Created By:	Fabio Pandini, Wind	**Last Updated By:**	Fabio Pandini, Wind
Date Created:	11.12.2013	**Last Revision Date:**	11.12.2013
Business Objectives:	• Reduce operational cost • Increase customer satisfaction • Improve the overall efficiency of the energy system		
Key Actors:	• DCO • Customer		
Value proposition:	• ***DC Operator:*** possibility to accept power consumption reduction request from Aggregators and so participate to demand response programs • ***DC Operator:*** has the opportunity of reorganising the distribution of ICT resources to Customers, so as to take into account the actual processing loads, which can lead to a more optimised utilization of ICT resources • ***End customer:*** possibility to choose between different SLA and to get service cost reduction if the end customer can accept some QoS variations		
Customer Segment:	End-users that accept to have a dynamic SLA renegotiation		
Revenue Stream:	• DC service cost reduction • More competitive offer from DC to end customers, therefore opportunity to increase DC market share		
Metrics:	• QoS of DC services to the end customers • DC service cost		
Related use cases:	UC.2.3.1 – UC.2.3.2 – UC.2.3.3		
SLAs involved:	DCO to end-customer SLA		
Assumptions:	• The DC operator should have an automatic control system to interact with the end customer's systems and dynamically renegotiate the SLA • The end customer should also have such an automatic control system		

Table 4-5: SLA Renegotiation with end customers

4.4. Improve the quality of the energy mix towards environmental "friendliness"

4.4.1. Green-powered service to end customers:

Improving a DC's KPI index is the main objective of the DCO in this class of BS, and one means of achieving this is to introduce renewable energy co-generation systems. Co-generated energy will ultimately alter the energy budget of the DC by lowering the total power expenditure and OPEX, which in turns allows the DCO to achieve better service costs and be more competitive.

BS ID:	BS.3.1		
BS Name:	Green-powered service to end customers		
Created By:	Antonios Kollaras, IRT	**Last Updated By:**	Antonios Kollaras, IRT
Date Created:	20.12.2013	**Last Revision Date:**	20.12.2013
Business Objectives:	• Reduce operational costs • Increase customer satisfaction • Stimulate the adoption of green energy		
Key Actors:	• DCO • End Customers • Utility/Aggregators		
Value proposition:	• ***DCO:*** green SLA to the End Customers, in which are specified the percentage of renewable energy used for the services provisioning. • ***Utility/Aggregators:*** provides an energy mix from renewable sources		
Customer Segment:	• Customers which are attracted by the prospective of potentially lower SLAs in exchange to lower service costs • Customers with ethical behaviour that are attracted by the possibility of experiencing services when it is proved that they are offered with low environmental impact.		
Revenue Stream:	• Larger revenue thanks to considerably lower energy expenditure costs • Revenues achieved from an improved customer base, thanks also to the adoption of ethical behaviour to acquire market/reputation (increase their satisfaction using green services).		
Metrics:	• Green energy percentage usage (i.e. KPI of use of renewable energy) • Customer service quality (customer satisfaction)		
Related use cases:	UC.3.1.1 – UC.3.1.2 – UC.3.1.3		
SLAs involved:	• DCO to Customer SLA • DCO to DCO SLA • DCO to Utility/Aggregators SLA		
Assumptions:	Data Centre Operator can exhibit some sort of Green-powered certification to sponsor its services to customers		

Table 4-6: Green-powered service to end customers

4.4.2. Optimize benefits/incentives from national/European authorities

Companies which choose to invest in projects to achieve better energy efficiency or green energy can opt in to receive benefits/incentives provided by national or EU Authorities (e.g. tax exemptions that directly influencing OPEX by lowering the total energy costs).

BS ID:	BS.3.2		
BS Name:	Optimize benefits/incentives from national/European authorities		
Created By:	Antonios Kollaras, IRT	**Last Updated By:**	Antonios Kollaras, IRT
Date Created:	20.12.2013	**Last Revision Date:**	20.12.2013
Business Objectives:	• Stimulate the adoption of green energy • Improve the overall efficiency of the energy system Data Centre		
Key Actors:	• DCO • Aggregators • Authorities (national/European) • Customers		
Value proposition:	This business scenario leverage on the fact that upon Data Centre Operators policy of utilizing green energies, they are granted with benefits from National/European authorities • ***DCO***: monitoring the consumption and handle dynamically the workload assets in respect of the energy metrics provided by the Authorities. Moreover interact with Aggregators for participating to demand/response programs. • ***Aggregators***: provides interface for participating to demand/response programs. • ***Authorities***: provides directives and KPIs for measuring the DCO energy efficiency. • ***Customers:*** support of SLA renegotiation to address the energy constraints		
Customer Segment:	No particular customer segments is forecasted for this scenario		
Revenue Stream:	DCO optimize the benefits received from national authorities for the green power policy. Those benefits could arrive in the form of lower taxation or directly as money streams. At the end they could be transformed in lower cost on a per service basis.		
Metrics:	• Green energy percentage usage (i.e. KPI of use of renewable energy) • KPIs for measuring Data Centres overall efficiency • Authority specific metrics		
Related use cases:	UC.3.2.1 – UC.3.2.2 – UC.3.2.3		
SLAs involved:	• DCO to Customer SLA • DCO to DCO SLA • DCO to Aggregators SLA		
Assumptions:	The benefits will vary from nation to nation. Data Centre operator with multiple presence in geographical diversity should properly compose the different stream granted by different authorities		

Table 4-7: Optimize benefits/incentives from national/European authorities

4.4.3. Smart City

BS ID:	BS.3.3		
BS Name:	Smart City		
Created By:	Antonios Kollaras, IRT	**Last Updated By:**	Antonios Kollaras, IRT
Date Created:	20.12.2013	**Last Revision Date:**	20.12.2013
Business Objectives:	• Stimulate the adoption of green energy • Reduce operational costs • Increase customer satisfaction • Improve the overall efficiency of the energy system		
Key Actors:	• DCO • Customers • Aggregator/Utility		
Value proposition:	• ***DCO:*** possibility to accept power consumption reduction request from Aggregators and so participate to demand response programs • ***Customers***: support of SLA renegotiation to address the energy constraints • ***Aggregator/Utility***: ability to monitor the global energy consumption at the city level and propose to the DCO the participation to the demand response programs to achieve energy stabilization.		
Customer Segment:	No particular customer segments is forecasted for this scenario		
Revenue Stream:	• DC service cost reduction • Possible acquisition of energy efficiency certificates		
Metrics:	• KPIs for measuring Data Centres overall efficiency • QoS of the electric power grid		
Related use cases:	UC.3.3.1 – UC.3.3.2 – UC.3.3.3		
SLAs involved:	• DCO to Customer SLA • DCO to DCO SLA • DCO to Utility/Aggregators SLA		
Assumptions:	• A Smart grid should exist and the aggregator should be connected to it • The DC operator should have an automatic control system to interact with the smart grid • The DC operator should have an automatic control system to interact with the end customer's systems and dynamically renegotiate the SLA		

Table 4-8: Smart City

5. Use Case Description

5.1. Introduction

Similar to Business scenarios, we have selected a common template to allow for a complete and coherent instantiation of the UCs. The template is described in Table 5-1. The template comprises all the main aspects useful to describe every identified use case, like Business Objectives, Key Actors, Revenue Stream, Customer Segment, as well as information regarding Pre/Post-conditions, Normal and Alternative flow.

Use Case ID:	A globally unique identification of the Use Case
Use Case Name:	A user-defined identification. Preferably a short active verb phrase describing the goal to be reached, the purpose of the Use Case
Created By:	**Last Updated By:**
Date Created:	**Last Revision Date:**
Business Objectives:	The Business Objective(s) addressed by this Use case
Actors:	Specifies which (human and computer) actors are part of the Use Case (should be named in the list of actors)
Description:	A brief summary of objectives and functions of the Use Case
Customer Segment:	Various set of customers can be segmented based on the different needs and attributes: Mass Market, Niche Market, Segmented, Diversify, Multi-Sided Platform / Market.
Revenue Stream:	The way a company makes income from each customer segment. Several ways to generate a revenue stream: Asset Sale, Usage Fee, Subscription Fees, Lending/Leasing/Renting, Licensing, Brokerage Fees, Advertising…
Trigger:	Set of events that lead to the Use Case action flow.
Preconditions:	The use cases that should be executed prior to this one.
Post conditions:	The scenarios that can be achieved if the current use case succeed.
Normal Flow:	The data, actions, and events required to trigger the corresponding function
Exceptions:	Particular situations in which the target cannot be achieved
Frequency of Use:	Number of times per week the scenario could be "activated"
Assumptions:	Conditions that can be assumed to be already present
Risks:	Events that could prevent to reach the Business Objectives
OPEX Analysis	This is a brief analysis of the Impact at the operational costs that must be sustained to realize the Use Case

Table 5-1: Structure of Use Case

5.2. Energy efficient workload redistribution

5.2.1. Using a Single DC

Use Case ID:	UC.1.1		
Use Case Name:	Energy efficient workload redistribution using a single DC		
Created By:	Fabio Pandini, Wind	**Last Updated By:**	Fabio Pandini, Wind
Date Created:	28-11-2013	**Last Revision Date:**	28-11-2013
Business Objectives:	Reduce operational costs (by reducing the total energy consumed and the related cost, in consistency with the SLAs)		
Actors:	• DCO • Customer		
Description:	When the overall DC efficiency reaches a given threshold, the DC Operator can perform: • Re-organisation or adjustment of workload (typically Virtual Machines) among servers (physical machines) • Adjustment of CPU frequency operation • Shutting down of ICT devices or HVAC devices • In general other actions that can bring down the energy consumption		
Customer Segment:	Customers that have explicitly accepted the option of having their SLAs renegotiated, when the need arises.		
Revenue Stream:	• Reduce the operational cost, with a potential decrease of service fees, having, however, a positive balance. • Benefits from energy efficiency certificates		
Trigger:	The energy efficiency of the DC is sub-optimal		
Preconditions:	• The DC consists of ICT devices with energy saving capabilities and supports automatic HVAC control • The DC supports Virtual Machine migration • Existence of a SLA negotiation framework		
Post conditions:	The DC optimization actions do not violate the signed customer contracts		
Normal Flow:	A sub-optimal DC operation state is detected. Then, an automatic algorithm is executed that identifies the actions that could be taken to optimize the DC energy state. If necessary, SLAs renegotiation takes place. Then, the identified actions are being performed to reduce the total energy consumption. Examples of such actions include: 1. Virtual Machine migration/shut down 2. ICT devices power management (shut down, DVFS, etc) 3. Application of HVAC related actions (shut down, scaling, etc)		
Exceptions:	• *Case 1: No optimization actions have been identified* The DC continues its operation without performing any changes • *Case 2: The customers cannot be contacted during the renegotiation* Only apply the actions that do not require SLA renegotiation • *Case 3: Failure in performing the identified actions* The DC operation falls back to its previous state		
Frequency of Use:	Every time the trigger is fired		
Assumptions:	A range of SLA options is foreseen at the contract level and is available to the project		
Risks:	• Data loss		

	• System and power instability • Hardware failure • Network failure • Temporal SLA violation
OPEX Analysis	The overall energy consumption of the DC is expected to be lowered.

Table 5-2: Workload redistribution using a single DC

5.2.2. Using a Synergetic DC of the same administrative Domain

Use Case ID:	UC.1.2		
Use Case Name:	Energy efficient workload redistribution using synergetic DC of the same administrative Domain		
Created By:	Fabio Pandini, Wind	**Last Updated By:**	Fabio Pandini, Wind
Date Created:	28-11-2013	**Last Revision Date:**	19-12-2013
Business Objectives:	Reduce operational costs (by reducing the total energy consumed and the related cost, in consistency with the SLA)		
Actors:	• DCOs of the same administrative domain • Customer		
Description:	Some Data Centres of the administrative domain could find profitable to increase the computational workload in order to get a higher power efficiency. In this case these Data Centres can send a request to the other Data Centres to get part of their workload. This way the overall efficiency of the DC network could be improved.		
Customer Segment:	In this case, the "customer" is actually the DC Operator.		
Revenue Stream:	• Reduce the energy cost. • Benefits from energy efficiency certificates.		
Trigger:	Based on the Data Centres metrics, the power efficiency could be improved		
Preconditions:	• Each DC taking role in the initiative has already agreed to participate in a Demand-Response Program for achieving efficient energy workload distribution among two or more synergetic Data Centres of the same administrative domain. • There is an operational interface established between the participating Data Centres. • There is at least one synergetic DC of another administrative domain which is willing to lower its workload and is able to migrate it toward the originator DC.		
Postconditions:	The power consumption for the originator DC becomes more balanced, while the workload (and associated power consumption) in the responding DC(s) lowers. This may also allow responding Data Centres to better consolidate their resource usage and lower their total power consumption.		
Normal Flow:	1. One of the DC informs the other Data Centres of the possibility to increase its workload, describing also the details and characteristics of the services that can be accepted. 2. The other Data Centres evaluate the possibility to migrate part of their workload depending on the QoS that the originating DC can guarantee and		

	send their responses. 3. The originator DC evaluates which Data Centres workload, from those that responded positively, can be accepted and send the corresponding information to start the workload transfer. 4. The involved Data Centres start the procedures to migrate part of their workload to the originating DC.
Exceptions:	Case 1: There are no synergetic Data Centres available to migrate the workload and able to carry out the migrated workload under the expected SLA. In this case, the initial request of availability from the originating DC is terminated due to time-out.
Frequency of Use:	Every time the trigger is fired
Assumptions:	Data Centres taking role in the synergetic network of Data Centres from different administrative domains have agreed upon, and established a framework which allows workload to migrate between two Data Centres, under certain specific conditions.
Risks:	• Data loss • Hardware failure • Network failure • Temporal SLA violation
OPEX Analysis	The overall energy cost of the Data Centres network is expected to be lowered.

Table 5-3: Workload redistribution using synergetic DC of the same administrative Domain

5.2.3. Using a Synergetic DC of alternative administrative Domain

Use Case ID:	UC.1.3		
Use Case Name:	Energy efficient workload redistribution using synergetic DC of alternative administrative Domain		
Created By:	Antonios Kollaras, IRT	**Last Updated By:**	Antonios Kollaras, IRT
Date Created:	28-11-2013	**Last Revision Date:**	19-12-2013
Business Objectives:	Reduce operational costs (Joint effort of two or more DCOs to reduce the total energy consumed and the related cost, in consistency with everyone's established SLAs)		
Actors:	• DCOs of different administrative domains • Customer		
Description:	• DCOs of different administrative domains of Data Centres (subject to varying energy fees and availability) may find profitable to establish protocols that allow them to migrate workloads between Data Centres in a demand/acknowledge fashion. • This allows to better exploiting resources of those Data Centres that would otherwise fail to achieve optimal energy efficiency.		
Customer Segment:	In this case, the "customer" is actually the DC Operator.		
Revenue Stream:	• Reduce the energy cost • Reduce the OPEX by accessing lower energy fees • Benefits from energy efficiency certificates		
Trigger:	Based on the Data Centres metrics, the power efficiency could be improved		
Preconditions:	• Each DC taking role in the initiative has already agreed to participate in a		

	Demand-Response Program for achieving efficient energy workload distribution among two or more synergetic Data Centres of different administrative domain. • There is an operational interface established between the participating DC • There is at least one synergetic DC of another administrative domain which is willing to raise its workload and is able to migrate workload from other participating Data Centres
Postconditions:	The power consumption for the originator DC becomes more balanced, while the workload (and associated power consumption) in the responding DC(s) lowers. This may also allow responding Data Centres to better consolidate their resource usage and lower their total power consumption.
Normal Flow:	1. One of the Data Centres informs the others of the possibility to raise its total operating workload by migrating workload from other Data Centres, describing also the details and characteristics of the services made available. The originator DC should always inform others Data Centres in accordance with the SLAs that sign the rules for participating to the Demand-Response Program. 2. The other Data Centres evaluate the possibility to migrate part of their workload depending on the QoS that the originating DC can guarantee and send their responses. 3. The originator DC evaluates which Data Centres workload, from those that responded positively, can be accepted and send the corresponding information to start the workload transfer. 4. The involved Data Centres start the procedures to migrate part of their workload to the originating DC. 5. Ideally, some form of accounting is established among all participants DCOs, in order to redistribute benefits resulting from energy savings and shared expenses.
Exceptions:	***Case 1:*** There are no synergetic Data Centres available to migrate the workload and able to carry out the migrated workload under the expected SLA. In this case, the initial request of availability from the originating DC is terminated due to time-out.
Frequency of Use:	Every time the trigger is fired
Assumptions:	Data Centres taking role in the synergetic network of Data Centres from different administrative domains have agreed upon, and established a framework which allows workload to migrate between two Data Centres, under certain specific conditions.
Risks:	• Data loss • Hardware failure • Network failure • Temporal SLA violation
OPEX Analysis	• The overall energy cost of the Data Centres network is expected to be lowered. • The energy expenditure per work unit (including the overhead costs needed to perform the migration) for "migrating Data Centres" is expected to be lowered.

Table 5-4: Workload redistribution using synergetic DC of alternative administrative Domain

5.3. Multi tariffs from the Utility companies

5.3.1. Using a Single DC

Use Case ID:	UC.2.1.1		
Use Case Name:	Multi tariffs from the Utility companies in the case of a single DC		
Created By:	Georgios Goumas, GRNET	**Last Updated By:**	Dimitris Siakavaras, GRNET
Date Created:	23/12/2013	**Last Revision Date:**	7/1/2014
Business Objectives:	• Reduce operational costs • Improve the overall efficiency of the energy system		
Actors:	• DC Operator • Aggregator • Utility Operator		
Description:	In case the energy cost can vary during the day or the week the workload can be regulated in order to reduce the overall cost. To obtain this goal the DC operators can: • Postpone part of the workload in more convenient time slot. • Adjust the CPU frequency and Voltage operation.		
Customer Segment:	DCO		
Revenue Stream:	Energy cost reduction taking advantage of the different tariffs from the Utility companies.		
Trigger:	The electricity demand rise over a certain threshold during the slot time with less convenient tariff		
Preconditions:	• Multi tariffs agreement from the Energy provider • An efficient workload management system must be adopted so that the workload can be postponed • The DC consists of ICT devices with energy saving capabilities and supports automatic HVAC control.		
Postconditions:	The DC consumption remains within the boundaries of the Target Consumption and a significant part of the workload is shifted in the most convenient time slot		
Normal Flow:	1. The DC Operators have different agreements with the local energy providers, with different tariffs in different time slots (the tariffs may also change dynamically based on the state of the power distribution grid) 2. The DC operator can evaluate if there could be an advantage in moving part of the current workload to a more convenient time slot, or in adjusting CPU frequencies and Voltage operation. 3. The relative workloads are time-shifted accordingly to the directions given		
Exceptions:	*1.* The lowering of the performance level is not acceptable by customers *2.* The workload cannot be shifted to different hours.		
Frequency of Use:	Hourly, based on the agreement with the energy providers and the hourly energy tariffs		
Assumptions:	• A Smart grid should exist and the aggregator should be connected to it • The DC operator should have an automatic control system to interact with the smart grid		

Risks:	• Data loss • System and power instability • Hardware failure • Network failure • Temporal SLA violation
OPEX Analysis:	The overall energy cost of the DC is expected to be lowered.

Table 5-5: Electricity multi tariffs in the case of a single DC

5.3.2. Using a Synergetic DC of the same administrative Domain

Use Case ID:	UC.2.1.2		
Use Case Name:	Multi tariffs from the Utility companies using a Synergetic DC of the same administrative Domain		
Created By:	Nikos Nikolaou, SYN	**Last Updated By:**	Nikos Nikolaou, SYN
Date Created:	17-12-2013	**Last Revision Date:**	17-12-2013
Business Objectives:	• Reduce the operational costs (by switching the workload to Data Centres where electricity prices are lower). • Improve the overall efficiency of the energy system		
Actors:	• DCO • Utility Operator • Authorities		
Description:	The DCO receives from the Utility Operator the electricity pricing scheme. Based on the multi-tariff pricing scheme, the DCO can do the following: 1. During the periods of peak electricity prices, the DCO can migrate ICT workload towards one of the available synergetic Data Centres that belong in the same administrative domain, without increasing the service cost towards the Customer. 2. During periods where the cost of electricity is less, the DCO can undertake the processing of ICT workload from a synergetic DC of the same administrative domain.		
Customer Segment:	This UC does not address a specific customer segment of the DC, since the benefits are targeting only the DCO or the Utility Operator.		
Revenue Stream:	• Reduce the operational cost of DCO, by decreasing the consumed quantity of energy that is charged under the higher rate tariff.		
Trigger:	This UC is not triggered by any specific event or action. It is expected to take place as a result of a planning from the DCO, so as to take advantage of the multi-tariffs offered by the Utility Operator. Once such a multi-tariff is changed or updated, the DCO will also have to revise its internal planning, too.		
Preconditions:	• The energy multi-tariff scheme is available and known in advance. • The DC supports Virtual Machine migration.		
Post conditions:	The DC optimization actions do not violate the signed customer contracts.		
Normal Flow:	Using a scheduling mechanism, based on the multi-tariff timings, an automatic algorithm is executed that identifies the actions that could be taken to optimize the DC energy state. These actions target either to migrate or to undertake ICT workload towards/from a synergetic DC of the same administrative domain. Since such actions will be taking place in a scheduled manner, if an SLA renegotiation is required, then this will have to be done well in advance, so as to avoid unnecessary delays when the actual energy optimisation actions need to		

	take place. Additionally, the DCO will also need to advertise in advance to any other synergetic DC the exact timings that it can operate under low-tariff energy. Following this, the DCO will collect information regarding the synergetic Data Centres and the type of the ICT load that they are willing to migrate. The energy optimisation actions could include only Virtual Machine migration.
Exceptions:	• Case 1: No synergetic DC is willing to participate in the low-tariff energy program advertised by the DCO o The DCO cannot take advantage of serving additional ICT workload while the energy tariff is low. • Case 2: The DC SLAs with the Customers during the high-tariff energy window do not allow their renegotiation or the migration of the respective ICT workload. o The DCO cannot perform any ICT workload migration.
Frequency of Use:	The frequency of this UC depends on how often the energy tariff changes within a single day. In the majority of the cases this should be relatively low, in the range of 2-4 times per day, maximum.
Assumptions:	
Risks:	• Data loss • Hardware failure • Network failure
OPEX Analysis:	The energy cost of the DC is expected to decrease.

Table 5-6: Electricity multi tariffs using a Synergetic DC of the same administrative Domain

5.3.3. Using a Synergetic DC of different administrative domains

Use Case ID:	UC.2.1.3		
Use Case Name:	Multi tariffs from the Utility companies		
Created By:	Fabio Pandini, Wind	**Last Updated By:**	Fabio Pandini, Wind
Date Created:	28-11-2013	**Last Revision Date:**	19-12-2013
Business Objectives:	• Reduce the operational costs (by switching the workload to Data Centres where electricity prices are lower). • Improve the overall efficiency of the energy system		
Actors:	• DC Operators • Aggregator		
Description:	In case the energy cost can vary during the day or the week the workload can be regulated in order to reduce the overall cost. To obtain this goal the DC operators can: • Postpone part of the workload in more convenient time slot • Move part of the workload to a DC that have more convenient energy tariff in that moment		
Customer Segment:	DC Operators		
Revenue Stream:	• Energy cost reduction taking advantage of the different tariffs from the Utility companies		
Trigger:	The electricity demand rise over a certain threshold during the slot time with less convenient tariff		
Preconditions:	• Multi tariffs agreement from the Energy provider • An efficient workload management system must be adopted so that the workload can be postponed or moved to more convenient Data Centres		

	without going below the performance limit requested by the users
Post conditions:	The DC consumption remains within the boundaries of the Target Consumption and a significant part of the workload is shifted in the most convenient time slot or moved to DC with lower tariffs.
Normal Flow:	1. The DC Operators have different agreements with the local energy providers, with different tariffs in different time slots (the tariffs may also change dynamically based on the state of the power distribution grid) 2. Every DC in the federation periodically publish its availability to accept external workload, along with the corresponding tariffs 3. Every DC in the federation can thus evaluate if there could be an advantage in moving part of its workload to other Data Centres where energy prices are lower, and sends a workload migration request 4. The destination DC selects the migration requests that can be accepted, and sends back a positive reply 5. The relative workloads are moved accordingly to the directions given
Exceptions:	1. The lowering of the performance level is not acceptable by customers 2. The workload cannot be shifted to different hours. 3. The workload cannot be moved to other Data Centres
Frequency of Use:	Hourly, based on the agreement with the energy providers and the hourly energy tariffs
Assumptions:	• A Smart grid should exist and the aggregator should be connected to it • The DC operator should have an automatic control system to interact with the smart grid
Risks:	• Data loss • System and power instability • Hardware failure • Network failure • Temporal SLA violation
OPEX Analysis	The overall energy cost of the Data Centres network is expected to be lowered.

Table 5-7: Electricity multi tariffs

5.4. Flexible contract between the Utility, the Smart Grid and the DC owner

5.4.1. Using a Single DC

Use Case ID:	UC.2.2.1		
Use Case Name:	Flexible contract between the utility, the SmartGrid and the DC owner in the case of a single DC		
Created By:	Georgios Goumas	**Last Updated By:**	Dimitris Siakavaras
Date Created:	23/12/2013	**Last Revision Date:**	7/1/2014
Business Objectives:	• Increase customer satisfaction. • Reduce operational costs		
Actors:	• DCO • Aggregator		
Description:	The Utility can offer the DC a reduction of energy cost in case the DC can respond positively to energy reduction request. When a DC receives a request from the Utility the energy absorption can be lowered through: • Performance reduction • Workload shift in different time slots		
Customer Segment:	DC Operator		
Revenue Stream:	• Energy cost reduction.		
Trigger:	When the overall load on the energy network reach a certain value the Utility send a request to the DC operator in order to reduce the power consumption		
Preconditions:	• Agreement between DC operator and Utility to lower energy cost if the request of the energy provider are met • An efficient power management system must be adopted so that the power consumption can be lowered • DC operator must be able to shift the workload • The DC consists of ICT devices with energy saving capabilities and supports automatic HVAC control.		
Post conditions:	The energy network load remains within the boundaries of the Target Consumption.		
Normal Flow:	1. The DC Operator gets an agreement with the Energy provider for a reduction of rates if the request for load reduction are met. 2. If the power goes over the fixed limit the Utility send to the DC Operator a request in order to reduce the power absorption. 3. The DC operator evaluate the request and see if it can be done in two ways: • Lower the performance of the DC • Postpone part of the workload 4. The DC Operator responds back to the Utility that it would comply with the request and performs the required actions.		
Exceptions:	The power reduction request cannot be accomplished because the workload cannot be postponed.		
Frequency of Use:	Hourly, based on the power grid dynamics		

Assumptions:	• A Smart grid should be in place and the aggregator should be connected to it • The DC operator should have an automatic control system to interact with the smart grid
Risks:	• Data loss • System and power instability • Hardware failure • Network failure • Temporal SLA violation
OPEX Analysis:	The energy cost of the DC is expected to be lowered.

Table 5-8: Flexible contract (single DC)

5.4.2. Using a Synergetic DC of the same administrative Domain

Use Case ID:	UC.2.2.2		
Use Case Name:	Flexible contract between the Utility, the Smart Grid and the DC owner using a Synergetic DC of the same administrative Domain		
Created By:	Nikos Nikolaou, SYN	**Last Updated By:**	Nikos Nikolaou, SYN
Date Created:	27-12-2013	**Last Revision Date:**	27-12-2013
Business Objectives:	• Reduce operational costs • Improve the overall efficiency of the energy system (by achieving a smoother consumption of energy over the smart grid throughout the day) • Increase the availability and reliability of DC federation		
Actors:	• DC Operator • Aggregator • Utility Operator		
Description:	The Utility Operator can offer the DC flexible contracts that reduce the energy cost in case the DCO responds positively to energy reduction requests. This UC tries to take advantage of such contracts, primarily, in order to achieve smoother energy loads on the smart grid throughout the day, while decreasing the energy cost for the DCO. Considering that there is a contract between the Utility Operator and the DCO that foresees specific benefits for the DCO, when a DCO receives a request from the Aggregator, on the basis of such a contract, the DCO will have to treat that request with high priority. In this context, the energy reduction can be achieved through: • Migration of stand-by or batch services to a synergetic DC of the same administrative domain • Workload migration towards synergetic Data Centres of the same administrative domain		
Customer Segment:	This UC does not address a specific customer segment of the DC, since the benefits are targeting only the DCO or the Utility Operator.		
Revenue Stream:	• Energy cost reduction		
Trigger:	When the overall load on the energy network reach a certain value the Utility send a request to the DCO in order to reduce the power consumption.		
Preconditions:	• Agreement between Utility Operator and DCO that the former will lower the energy cost if the latter responses positively to a relevant request for		

	decreasing the energy consumption. • An efficient power management system must be adopted so that the power consumption can be lowered. • DCO must be able to shift the workload.
Post conditions:	The energy network load remains within the boundaries of the Target Consumption.
Normal Flow:	1. The DC Operator gets a contractual agreement with the Utility Operator for a reduction of energy rates if a request for reducing energy consumption is met. 2. The Aggregator is also informed about the special contract between the Utility Operator and the DCO. 3. In order to achieve a smoother consumption of energy within a day, the Aggregator sends to the DCO a request to reduce the power consumption. 4. The DCO processes the request with high priority and determines the ways that can be employed to positively respond to the request: • Migration of stand-by or batch services to a synergetic DC of the same administrative domain. • Workload migration towards synergetic Data Centres of the same administrative domain. 5. If it is deemed necessary, and SLA renegotiation might also take place. 6. The DCO communicates back to the Aggregator the results of the request assessment and initiates the execution of the necessary energy optimisation actions.
Exceptions:	The power reduction request cannot be accomplished because the workload cannot be moved to other Data Centres.
Frequency of Use:	This highly depends on the smart grid dynamics and the energy consumption peaks that can be observed within a day. Usually, it could take place 3-4 times per day, or event more, but not significantly.
Assumptions:	• A Smart grid should exist and the aggregator should be connected to it • The DC operator should have an automatic control system to interact with the smart grid
Risks:	• Data loss • System and power instability • Hardware failure • Network failure • Temporal SLA violation
OPEX Analysis:	The overall energy cost of the Data Centres network is expected to be lowered.

Table 5-9: Flexible contract (Synergetic DC/ the same administrative domain)

5.4.3. Using a Synergetic DC of alternative administrative Domain

Use Case ID:	UC.2.2.3		
Use Case Name:	Flexible contract between the Utility, the Smart Grid and the DC owner		
Created By:	Fabio Pandini, Wind	**Last Updated By:**	Fabio Pandini, Wind
Date Created:	28-11-2013	**Last Revision Date:**	19-12-2013
Business Objectives:	• Reduce operational costs • Improve the overall efficiency of the energy system • Increase the availability and reliability of DC federation		
Actors:	• DC Operators • Aggregator		
Description:	The Utility can offer the DC a reduction of energy cost in case the DC can respond positively to energy reduction request. When a DC receive a request from the Utility the energy absorption can be lowered through: • Performance reduction • Workload shift in different time slots • Workload moving to other Data Centres		
Customer Segment:	DC operator		
Revenue Stream:	• Energy cost reduction		
Trigger:	When the overall load on the energy network reach a certain value the Utility send a request to the DC operator in order to reduce the power consumption		
Preconditions:	• Agreement between DC operator and Utility to lower energy cost if the request of the energy provider are met • An efficient power management system must be adopted so that the power consumption can be lowered • DC operator must be able to shift the workload		
Post conditions:	The energy network load remains within the boundaries of the Target Consumption.		
Normal Flow:	1. The DC Operator gets an agreement with the Energy provider for a reduction of rates if the request for load reduction are met. 2. If the power goes over the fixed limit the Utility send to the DC Operator a request in order to reduce the power absorption. 3. The DC operator evaluates the request and checks if it can be done in three ways: • Lower the performance of the DC • Postpone part of the workload • Move part of the workload to other Data Centres of different domains 4. In case the workload must be moved to other Data Centres of different domains, a negotiation must be activated between DC operators in order to agree on this 5. If the negotiation succeeds and the workload can be moved, the DC Operator responds back to the Utility that it would comply with the request		
Exceptions:	The power reduction request cannot be accomplished because the workload cannot be moved to other Data Centres		
Frequency of Use:	hourly, based on the power grid dynamics		
Assumptions:	• A Smart grid should exist and the aggregator should be connected to it • The DC operator should have an automatic control system to interact with		

	the smart grid
Risks:	• Data loss • System and power instability • Hardware failure • Network failure • Temporal SLA violation
OPEX Analysis:	The overall energy cost of the Data Centres network is expected to be lowered.

Table 5-10: Flexible contract (Synergetic DC/different administrative domains)

5.5. SLA Renegotiation with end customers

5.5.1. Using a Single DC

Use Case ID:	UC.2.3.1		
Use Case Name:	SLA Renegotiation with end customers in the case of a single DC		
Created By:	Georgios Goumas, GRNET	**Last Updated By:**	Dimitris Siakavaras, GRNET
Date Created:	23/12/2013	**Last Revision Date:**	7/1/2014
Business Objectives:	• Increase the performance of offered services • Increase customer satisfaction • Reduce operational costs		
Actors:	• DC Operators • Customer		
Description:	SLAs with end customers could be renegotiated to take into account the energy consumption. In case the customer accepts a reduction of the performance he can obtain a price reduction. A fast renegotiation system could be implemented in order to benefit from particular situations (for instance a variation of the energy tariffs from the utility)		
Customer Segment:	DC service users		
Revenue Stream:	• Energy cost reduction • DC service cost reduction • More competitive offer from DC to end customers, therefore opportunity to increase DC market share		
Trigger:	When the overall workload reach a certain level the system operates a reduction of performance or a shift of the workload		
Preconditions:	• An efficient power management system must be adopted so that the power consumption can be lowered • Customers must accept lower performance level or to shift the workload		
Post conditions:	• The DC consumption remains within the boundaries of the Target Consumption and a significant part of the workload is shifted in the most convenient time slot • The DC optimization actions do not violate the signed customer contracts		
Normal Flow:	1. The DC renegotiates the SLAs with the end customers in order to take into		

	account variation of the QoS to get better power efficiency 2. When there is a workload that can be shifted in a more convenient time period, the DC operator evaluates when it could be re-scheduled respecting the SLAs in place. 3. If some of the end customers accept the new conditions in exchange of economic incentives, the workload shift can start.
Exceptions:	The lowering of the performance level is not acceptable by customers
Frequency of Use:	Hourly, based on the agreement with the energy providers and the hourly energy tariffs
Assumptions:	• A Smart grid should exist and the aggregator should be connected to it • The DC operator should have an automatic control system to interact with the smart grid • The end customer should accept the renegotiation of the SLA
Risks:	• Data loss • System and power instability • Hardware failure • Network failure • Temporal SLA violation
OPEX Analysis:	The energy cost of the DC is expected to be lowered.

Table 5-11: SLA Renegotiation with end customers (single DC)

5.5.2. Using a Synergetic DC of the same administrative Domain

Use Case ID:	UC.2.3.2		
Use Case Name:	SLA Renegotiation with end customers Using a Synergetic DC of the same administrative Domain		
Created By:	Nikos Nikolaou, SYN	**Last Updated By:**	Nikos Nikolaou, SYN
Date Created:	30-12-2013	**Last Revision Date:**	30-12-2013
Business Objectives:	• Reduce operational cost • Increase customer satisfaction • Increase the performance of offered services		
Actors:	• DCO • Customer		
Description:	The DCO identifies resource-demanding SLAs with a processing workload that is much lower than the expected one. This presents a clear opportunity to readjust those SLAs to more pragmatic levels and, simultaneously, decrease the respective ICT charges. The identified Customers' SLAs are clear candidates for renegotiation. Any reduction of an SLA will be accompanied by a reduction of the ICT service provisioning costs.		
Customer Segment:	Customers that accepted to have their SLA renegotiated.		
Revenue Stream:	• More efficient utilization of the ICT resources		
Trigger:	SLAs are identified that correspond to ICT resources that are actually only partial utilised.		
Preconditions:	• An efficient power management system must be adopted so that the power consumption can be lowered.		

	• Customers must accept lower performance level or to shift the workload.
Post conditions:	The DC consumption remains within the boundaries of the Target Consumption and a significant part of the workload is shifted in the most convenient time slot.
Normal Flow:	1. The DCO determines resource-demanding SLAs, which, however, do not exhibit high ICT workloads. 2. The DCO creates a list of Customers that could potentially be serviced under lower SLAs. Historical data could also be used for the creation of that list. 3. The DCO renegotiates with those Customers less demanding SLAs. 4. Through the SLA renegotiation process a set of ICT resources will become available. Every DC in the federation will periodically publish its availability to accept external workload, along with the corresponding conditions (price, guaranteed QoS, time, etc.). 5. When a single DC needs to move away some of its workload, it evaluates where it could be moved respecting the SLAs in place; note that the SLAs must also contain a list of Data Centres approved by the end customers for migration. 6. The originating DC evaluates which of the other Data Centres can better respond to its needs and constraints, and starts the workload migration process.
Exceptions:	The Customer, during the SLA renegotiation process, does not accept to have an SLA with lower performance. In this case, that particular Customer can be put in a monitoring status, so as to be rechecked in the near future, in case the actual utilisation of ICT resources still falls behind compared to the ICT resources projected by the SLA.
Frequency of Use:	This type of SLA renegotiation process is expected to take place on regular intervals, for instance once per week, fortnight or month.
Assumptions:	• A Smart grid should exist and the aggregator should be connected to it • The DC operator should have an automatic control system to interact with the smart grid • The end customer should accept the renegotiation of the SLA
Risks:	• Data loss • System and power instability • Hardware failure • Network failure • Temporal SLA violation
OPEX Analysis:	The SLA renegotiation process can help to rationalise the distribution of ICT resources to Customers, considering the actual workloads that have been observed. This can lead to a better utilisation of ICT resources, which, in turn, could assist avoiding unnecessary investments on new ICT infrastructure, with an immediate impact on the DCO's OPEX figures.

Table 5-12: SLA Renegotiation with end customers (Synergetic DC /the same administrative domain)

5.5.3. Using a Synergetic DC of alternative administrative Domain

Use Case ID:	UC.2.3.3		
Use Case Name:	SLA Renegotiation with your customers Using a Synergetic DC of alternative administrative Domain		
Created By:	Fabio Pandini, Wind	**Last Updated By:**	Fabio Pandini, Wind
Date Created:	28-11-2013	**Last Revision Date:**	19-12-2013
Business Objectives:	• Reduce operational cost • Increase customer satisfaction • Increase the performance of offered services		
Actors:	• DC operator • End customers		
Description:	SLAs with end customers could be renegotiated to take into account the energy consumption. In case the customer accepts a reduction of the performance he can obtain a price reduction. A fast renegotiation system could be implemented in order to benefit from particular situations (for instance a variation of the energy tariffs)		
Customer Segment:	DC service users		
Revenue Stream:	• Energy cost reduction		
Trigger:	When the overall workload reach a certain level the system operates a reduction of performance or a shift of the workload		
Preconditions:	• An efficient power management system must be adopted so that the power consumption can be lowered • Customers must accept lower performance level or to shift the workload		
Postconditions:	The DC consumption remains within the boundaries of the Target Consumption and a significant part of the workload is shifted in the most convenient time slot.		
Normal Flow:	1. The different Data Centres renegotiate the SLAs with the end customers in order to take into account variation of the QoS to get better power efficiency 2. Every DC in the federation periodically publish its availability to accept external workload, along with the corresponding conditions (price, guaranteed QoS, time, etc.) 3. When a single DC needs to move away some of its workload, it evaluates where it could be moved respecting the SLAs in place; note that the SLAs must also contain a list of Data Centres approved by the end customers for migration 4. The originating DC evaluates which of the other Data Centres can better respond to its needs and constraints, and starts the workload migration process. 5. If no DC can meet these requirements, a fast renegotiation process between the originating DC and the end customers may start. 6. If some of the end customers accept the new conditions in exchange of economic incentives, the workload transfer request can start.		
Exceptions:	1. The lowering of the performance level is not acceptable by customers 2. The other Data Centres of the network cannot accept the workload transfer request		
Frequency of Use:	Hourly, based on the agreement with the energy providers and the hourly energy tariffs		
Assumptions:	• A Smart grid should exist and the aggregator should be connected to it • The DC operator should have an automatic control system to interact with the smart grid		

	• The end customer should accept the renegotiation of the SLA
Risks:	• Data loss • System and power instability • Hardware failure • Network failure • Temporal SLA violation
OPEX Analysis:	The overall energy cost of the Data Centres network is expected to be lowered.

Table 5-13: SLA Renegotiation with your customers (Synergetic DC/different administrative domains)

5.6. Green-powered service to end customers

5.6.1. Using a Single DC

Use Case ID:	UC.3.1.1		
Use Case Name:	Green-powered service to end customers in case of a single DC		
Created By:	Georgios Goumas, GRNET	**Last Updated By:**	Dimitris Siakavaras, GRNET
Date Created:	23/12/2013	**Last Revision Date:**	7/1/2014
Business Objectives:	• Stimulate the adoption of green energy • Increase customer satisfaction		
Actors:	• DCO • Authority • Aggregators • Customer		
Description:	The growth of renewable energy could enable, in the near future, to power at least in part a DC. This could allow the DC operators to offer to the end users the choice of getting some services powered by green energy. This may attract customers that are more sensible to green consciousness; this kind of users could also be prone to pay higher tariffs for having a green powered services. The use of green energy could also guarantee the DC operators a return on brand recognition.		
Customer Segment:	Mainly business users, especially SME that have moderate requirements in terms of processing workload (that could therefore be easily distributed wherever there is an opportunity to use renewable power)		
Revenue Stream:	• Attract more customers, opportunity to propose higher fees to environmentally-conscious customers • Indirectly can elevate the corporate positive identity		
Trigger:	-		
Preconditions:	• The possibility to move part of the workload to a time period or to a part of the DC that uses renewable energy. • The energy sources of the entire DC group must be identified (i.e. we need to know when and where a given DC is powered by renewable sources)		
Post conditions:	A significant part of the energy used by the DC comes from renewable sources		
Normal Flow:	1. The end user is offered the possibility to choose between standard service and green service 2. The DC operator constantly monitors the power sources of each part of the DC. 3. The workload of the customers that accept the new offer is distributed according to their "green SLA" by an optimization algorithm		
Exceptions:	Too few customers willing to switch to green services		
Frequency of Use:	-		
Assumptions:			
Risks:	• Data loss		

	• System and power instability • Hardware failure • Network failure • Temporal SLA violation
OPEX Analysis:	Direct impact via lowering the CO2 footprint. Indirect impact via improving the brand recognition and increased customer base.

Table 5-14: Green-powered service to end customers (single DC)

5.6.2. Using a Synergetic DC of the same administrative domain

Use Case ID:	UC.3.1.2		
Use Case Name:	Green-powered service to end customers, using a Synergetic DC of the same administrative Domain		
Created By:	Kostas Pramataris, SYN	**Last Updated By:**	Kostas Pramataris, SYN
Date Created:	02-01-2014	**Last Revision Date:**	02-01-2014
Business Objectives:	• Increase customer satisfaction • Stimulate the adoption of green energy		
Actors:	• DCO • Customers		
Description:	Some of the synergetic Data Centres may be able to power part of their ICT equipment using energy derived from renewable sources and thus service part of their workload using renewable energy. Synergetic Data Centres can inform one another of their availability of remaining "green power" and in case a DC can accommodate extra workload powered by renewable energy, then a DC may relocate part of its workload to that DC. This ensures that when renewable energy is available at any of the Data Centres it will always be utilized. It is important to have a well-defined communication mechanism so that each DC knows exactly how much "green-powered" workload a synergetic DC can handle and also to have a fair algorithm for inter-DC workload relocations.		
Customer Segment:	This UC does not address a specific customer segment of the DC.		
Revenue Stream:	• Attract more environmentally-conscious customers.		
Trigger:	When a synergetic DC can accommodate extra workload that will be powered using energy from renewable-sources.		
Preconditions:	• An inter-DC communication platform must be in place that will enable the Synergetic Data Centres to inform one another of available renewable energy at each DC. • The possibility to move workload from one DC to another.		
Post conditions:	All renewable-energy is consumed first.		
Normal Flow:	1. A DC informs synergetic Data Centres that there is available renewable energy at the particular site and thus it can accommodate green-powered workload from other Data Centres. 2. One or more synergetic Data Centres may then shift part of their workload to that DC. 3. Each DC should dynamically update its "green-power" status and also monitor the status of the other synergetic Data Centres so as to dynamically relocate its workload if required.		

Exceptions:	None of the synergetic Data Centres can accommodate workload form other Data Centres that is powered by renewable energy.
Frequency of Use:	In the general case, the green-power availability of the Data Centres may change several times a day and consequently this mechanism could be triggered several times a day.
Assumptions:	• Data Centres that are partly powered using energy from renewable sources. • An inter-DC communication platform for exchanging green-power status.
Risks:	• Data loss • System and power instability • Hardware failure • Network failure • Temporal SLA violation
OPEX Analysis:	Direct impact via lowering the CO2 footprint and consequent tariffs. Lower the overall electricity cost of the administrative domain. Indirect impact via improving the brand recognition and increased customer base.

Table 5-15: Green-powered service to end customers (Synergetic DC/the same administrative domain)

5.6.3. Using a Synergetic DC of alternative administrative domain

Use Case ID:	UC.3.1.3		
Use Case Name:	Green-powered service to end customers		
Created By:	Fabio Pandini, Wind	**Last Updated By:**	Fabio Pandini, Wind
Date Created:	28-11-2013	**Last Revision Date:**	19-12-2013
Business Objectives:	• Increase customer satisfaction • Stimulate the adoption of green energy		
Actors:	• DCO • Authority • Aggregators • Customers		
Description:	The growth of renewable energy could enable, in the near future, to power at least in part a DC. This could allow the DC operators to offer to the end users the choice of getting some services powered by green energy. This may attract customers that are more sensible to green consciousness; this kind of users could also be prone to pay higher tariffs for having a green powered services. The use of green energy could also guarantee the DC operators a return on brand recognition.		
Customer Segment:	Mainly business users, especially SME that have moderate requirements in terms of processing workload (that could therefore be easily distributed wherever there is an opportunity to use renewable power)		
Revenue Stream:	• Attract more customers, opportunity to propose higher fees to environmentally-conscious customers • Indirectly can elevate the corporate positive identity		
Trigger:	-		
Preconditions:	• The possibility to move part of the workload to a green powered DC		

	• The energy sources of the entire DC group must be identified (i.e. we need to know when and where a given DC is powered by renewable sources)
Post conditions:	A significant part of the energy used by the Data Centres comes from renewable sources
Normal Flow:	1. The end user is offered the possibility to choose between standard service and green service 2. The DC operator constantly monitors the power sources of each DC belonging to its domain 3. The workload of the customers that accept the new offer is distributed according to their “green SLA” by an optimization algorithm
Exceptions:	Too few customers willing to switch to green services
Frequency of Use:	-
Assumptions:	
Risks:	• Data loss • System and power instability • Hardware failure • Network failure • Temporal SLA violation
OPEX Analysis:	Direct impact via lowering the CO2 footprint and consequent tariffs. Lower the overall electricity cost of the synergetic DC ecosystem. Indirect impact via improving the brand recognition and increased customer base.

Table 5-16: Green-powered service to end customers (Synergetic DC/different administrative domains)

5.7. Optimize benefits/incentives from national/European authorities

5.7.1. Using a Single DC

Use Case ID:	UC.3.2.1		
Use Case Name:	Optimize benefits/incentives from national/european authorities in the case of a single DC		
Created By:	Georgios Goumas, GRNET	**Last Updated By:**	Dimitris Siakavaras, GRNET
Date Created:	23/12/2013	**Last Revision Date:**	7/1/2014
Business Objectives:	Stimulate the adoption of green energy		
Actors:	• DCO • Utility Operator • Aggregators • Public Authorities		
Description:	The basic idea is to distribute the workload, and therefore the power consumption, among different parts of the DC or among different time periods with the objective of exploiting benefits and incentives from national or European authorities.		
Customer Segment:	Public Authorities, both at national and European level		
Revenue Stream:	• Public incentives for renewable energy (e.g. Green certificate, tax reduction)		
Trigger:	-		
Preconditions:	• Incentives and benefits from the authorities • DC operators must be able to shift the workload • The energy sources of the DC must be identified (i.e. we need to know when and where the DC is powered by renewable sources)		
Post conditions:			
Normal Flow:	1. The DC administrator understands that, for at least the next N hours, the energy cost can be lowered by time-shifting part of the workload. 2. The DC administrator checks whether the required actions can be performed (workload shifting, DVFS etc.) 3. The DC administrator performs the required actions.		
Exceptions:			
Frequency of Use:	Every time the DC can get a reduction of energy tariffs		
Assumptions:			
Risks:	• Data loss • System and power instability • Hardware failure • Network failure • Temporal SLA violation		
OPEX Analysis:	Direct impact from the Utility via special agreement to lower the peak load at specific time frames and avoid electricity network instability.		

Table 5-17 - Optimize benefits/incentives from national/European authorities (single DC)

5.7.2. Using a Synergetic DC of the same administrative domain

Use Case ID:	UC.3.2.2		
Use Case Name:	Optimize benefits/incentives from national/European authorities, using a Synergetic DC of the same administrative Domain		
Created By:	Kostas Pramataris, SYN	**Last Updated By:**	Kostas Pramataris, SYN
Date Created:	02-01-2014	**Last Revision Date:**	02-01-2014
Business Objectives:	• Stimulate the adoption of green energy		
Actors:	• DCO • Aggregators • Public Authorities		
Description:	It is possible that national and/or European authorities promote the shift of energy consumption from one region to another for environmental or other reasons. In that case, synergetic Data Centres of the same administrative domain located in different countries/regions may shift workload from one to another in order to benefit from the respective incentives.		
Customer Segment:	Public Authorities, both at national and European level		
Revenue Stream:	• Public incentives (i.e. Green certificates, tax reductions, etc.)		
Trigger:	-		
Preconditions:	• Incentives and benefits from national and/or European authorities • Ability to shift workload from one DC to another		
Postconditions:			
Normal Flow:	1. The DC administrator identifies that it is beneficial to shift the energy consumption from a DC that is located to one region to another DC at another region. 2. The DC administrator requests to the first DC to move some workload to the second DC. 3. The DC administrator also requests to the second DC to accept workload from another DC 4. If the network DC administrator receives both positive responses from the Data Centres the workload is moved.		
Exceptions:	The interested Data Centres cannot accept the workload transfer		
Frequency of Use:	Every time a DC can get a reduction of energy tariffs		
Assumptions:			
Risks:	• Data loss • System and power instability • Hardware failure • Network failure • Temporal SLA violation		
OPEX Analysis:	Direct impact from the Utility via special agreement to lower the peak load at specific time frames and avoid electricity network instability.		

Table 5-18: Optimize benefits/incentives from national/European authorities (Synergetic DC /the same administrative domain)

5.7.3. Using a Synergetic DC of alternative administrative Domain

Use Case ID:	UC.3.2.3		
Use Case Name:	Optimize benefits/incentives from national/European authorities		
Created By:	Fabio Pandini, Wind	**Last Updated By:**	Fabio Pandini, Wind
Date Created:	28-11-2013	**Last Revision Date:**	19-12-2013
Business Objectives	Stimulate the adoption of green energy		
Actors:	• DCO • Utility Operator • Aggregators • Public Authorities		
Description:	• The basic idea is to distribute the workload, and therefore the power consumption, among Data Centres of different domains that are physically located in different regions or countries with the objective of exploiting benefits and incentives from national or European authorities.		
Customer Segment:	Public Authorities, both at national and European level		
Revenue Stream:	• Public incentives for renewable energy (Green certificates, tax reductions, etc.)		
Trigger:	-		
Preconditions:	• Incentives and benefits from the authorities • DC operators must be able to shift the workload • The energy sources of the entire DC group must be identified (i.e. we need to know when and where a given DC is powered by renewable sources)		
Post conditions:			
Normal Flow:	1. The DC administrator understands that, for at least the next N hours, the energy cost in a particular country A is lower than the energy cost in another country B 2. The DC admin requests to a DC located in A to move some workload to DC in B 3. The DC admin requests to a DC located in B to accept part of the workload from another DC 4. If the network DC admin receives both positive responses from the Data Centres the workload is moved		
Exceptions:	The interested Data Centres cannot accept the workload transfer		
Frequency of Use:	Every time a DC can get a reduction of energy tariffs		
Assumptions:			
Risks:	• Data loss • System and power instability • Hardware failure • Network failure • Temporal SLA violation		
OPEX Analysis:	Direct impact from the Utility via special agreement to lower the peak load at specific time frames and avoid electricity network instability.		

Table 5-19: Optimize benefits/incentives from national/European authorities

5.8. Smart City

5.8.1. Using a Single DC

Use Case ID:	UC.3.3.1		
Use Case Name:	Smart City using Single DC		
Created By:	Georgios Goumas, GRNET	**Last Updated By:**	Dimitris Siakavaras, GRNET
Date Created:	16-01-2014	**Last Revision Date:**	16-01-2014
Business Objectives:	• Integration with the Smart City digital environment as a "prosumer" node, that is an entity that participates, in a smart way, in both energy consumption and energy generation • In this way, the DCOs can benefit from various incentives deriving from being part of a smart environment linked to the local municipality		
Actors:	• DCO • Authorities (Municipality and local Public Administrations) • Aggregator • Utility Operator (at local level, not only the local electrical utility, but also the utility in charge of district heating)		
Description:	In a Smart City a complex demand/response scheme can include electric power, renewable sources and heat. A DC could be involved in such a system and respond to the Smart City requests depending on its energy generation or modulation capability: • Heat exchange from the cooling system • Electric power absorption modulation • Electric power generation from renewable sources The heat generated could be reused in other structures of the city (swimming pools, building heating, etc.). Depending on the global electric consumption of the city, and the environmental objectives of the local municipality (e.g. reduction of CO_2 emissions), requests to modulate the energy absorption could be sent to the DC. In case the DC has a green power generation system (e.g. photovoltaic panels), green energy could be supplied to the city, depending on the workload situation of the DC and the actual objectives of the Smart City.		
Customer Segment:	No particular customer segments is forecasted for this scenario		
Revenue Stream:	• Revenues from selling excess or waste energy (if generated by the DC) • Possible acquisition of energy efficiency certificates • Possible incentives from the local municipality to participate to the Smart City		
Trigger:	When the Smart City send a request the DC operator evaluates the request and respond depending on its capability		
Preconditions:	• To supply energy to the Smart City, the DC should either have a generation plant installed (e.g. PV panels), or have excess energy to reuse (e.g. waste heat); the DC should also have a connection to the electrical power grid or the district heating network in order to deliver the energy generated • There must be a Smart City digital platform in place able to connect all the actors involved • The DCO must participate to the Smart City initiative		

Post conditions:	The municipality objectives related to energy use and environmental protection are more easily met. The DCO has the opportunity to better use or reuse its own energy generation capacity
Normal Flow:	1. The DC Operators receive a request from the Smart City system. 2. This request could include • Heat supply • Electric absorption reduction • Green energy supply 3. The DC operator evaluates if the request can be accomplished 4. In the positive case the DC operator sends its response to the Smart City 5. In the negative case the DC operator sends a negative response to the Smart City
Exceptions:	The Smart City request cannot be accomplished
Frequency of Use:	hourly, based on the Smart City dynamics
Special Requirements:	
Assumptions:	• An advanced demand/response system should be implemented with the Smart City • The DC operator should have an automatic control system to interact with the Smart City control system
Risks:	
OPEX Analysis	The overall energy cost of the DC is expected to be lowered. Direct impact from the Utility via special agreement to lower the peak load at specific time frames and avoid electricity network instability or even shell energy.

Table 5-20 - Smart City (Single DC)

5.8.2. Using a Synergetic DC of the same administrative Domain

Use Case ID:	UC.3.3.2		
Use Case Name:	Smart City using a Synergetic DC of the same administrative Domain		
Created By:	Kostas Pramataris, SYN	**Last Updated By:**	Kostas Pramataris, SYN
Date Created:	20-01-2014	**Last Revision Date:**	20-01-2014
Business Objectives:	• Stimulate the adoption of green energy • Reduce operational costs • Increase customer satisfaction • Improve the overall efficiency of the energy system		
Actors:	• DCO • Municipality and local/public Administrations.		
Description:	Within a “Smart-city ecosystem” several mechanisms could be in place in order to minimize and balance the overall power-consumption and promote the adoption of renewable energy resources. A DC could interoperate with such a Smart-city ecosystem and respond to respective energy-related requests. In special cases, a DC could also be interconnected with the municipal/public-section heating system and deliver DC-generated heat energy to that system.		

	The "smart-city" administrative system could inform the DC of possible "rush-hours" and also "idle-times" in the overall power distribution network and the DC could try to regulate its power consumption in accordance with these directives. In case a DC succeeds to conform to these directives, the DC could be awarded accordingly (i.e. lowered municipal taxes).
Customer Segment:	No particular customer segments is forecasted for this scenario.
Revenue Stream:	• Possible incentives from the local municipality (i.e. lowered taxes) • Revenues from selling excess heating energy generated by the DC. • Possible acquisition of energy efficiency certificates.
Trigger:	Smart City generated requests.
Preconditions:	• There must be a Smart City digital platform in place able to connect all the actors involved. • To supply heat energy to the Smart City, the DC should generate enough excess heat energy and there must be a municipal heating network in place able to accept this heat energy.
Post conditions:	
Normal Flow:	1. The Smart City system informs a particular DC Operator that the overall power dissipation is high and that reduction of the power consumption is essential. In another case the system may inform the DCO that enough renewable energy is at hand and that increase of the power dissipation is favourable, especially if generated heat is also utilized by the municipal heating system. 2. The DC communicates with other Data Centres in the same administrative domain but in different cities in order to identify the most appropriate DC to accommodate the currently active Virtual Machines. 3. In case the overall benefit justifies the respective risks, Virtual Machine migration from DC to DC could take place. 4. The DC informs the Smart City system of the final outcome. The results of the actions taken (i.e. reduced power consumption) should be visible anyhow by monitoring the respective resources.
Exceptions:	
Frequency of Use:	hourly, based on the Smart City system characteristics
Assumptions:	
Risks:	
OPEX Analysis:	The overall energy cost of the Data Centres network is expected to be lowered. Public incentives (i.e. lowered taxes) could also be earned. Direct impact from the Utility via special agreement to lower the peak load at specific time frames and avoid electricity network instability or even shell energy.

Table 5-21- Smart City (Synergetic DC/the same administrative domain)

5.8.3. Using a Synergetic DC of alternative administrative Domain

Use Case ID:	UC.7.3		
Use Case Name:	Smart City using a Synergetic DC of alternative administrative Domain		
Created By:	Fabio Pandini, Wind	**Last Updated By:**	Fabio Pandini, Wind
Date Created:	13-01-2014	**Last Revision Date:**	13-01-2014
Business Objectives:	• Stimulate the adoption of green energy • Reduce operational costs • Increase customer satisfaction • Improve the overall efficiency of the energy system		
Actors:	• DCO • Authorities (Municipality and local Public Administrations) • Aggregator • Utility Operator (at local level, not only the local electrical utility, but also the utility in charge of district heating)		
Description:	In a Smart City a complex demand/response scheme can include electric power, renewable sources and heat. A DC could be involved in such a system and respond to the Smart City requests depending on its energy generation or modulation capability: • Heat exchange from the cooling system • Electric power absorption modulation • Electric power generation from renewable sources The heat generated could be reused in other structures of the city (swimming pools, building heating, etc.). Depending on the global electric consumption of the city, and the environmental objectives of the local municipality (e.g. reduction of CO_2 emissions), requests to modulate the energy absorption could be sent to the DC. In case the DC has a green power generation system (e.g. photovoltaic panels), green energy could be supplied to the city, depending on the workload situation of the DC and the actual objectives of the Smart City.		
Customer Segment:	No particular customer segments is forecasted for this scenario		
Revenue Stream:	• Integration with the Smart City digital environment as a “prosumer” node, that is an entity that participates, in a smart way, in both energy consumption and energy generation • In this way, the DCOs can benefit from various incentives deriving from being part of a smart environment linked to the local municipality • Revenues from selling excess or waste energy (if generated by the DC) • Possible acquisition of energy efficiency certificates		
Trigger:	When the Smart City send a request the DC operator evaluates the request and respond depending on its capability		
Preconditions:	• To supply energy to the Smart City, the DC should either have a generation plant installed (e.g. PV panels), or have excess energy to reuse (e.g. waste heat); the DC should also have a connection to the electrical power grid or the district heating network in order to deliver the energy generated • There must be a Smart City digital platform in place able to connect all the actors involved • The DCO must participate to the Smart City initiative		

Post conditions:	The municipality objectives related to energy use and environmental protection are more easily met. The DCO has the opportunity to better use or reuse its own energy generation capacity
Normal Flow:	1. The DC Operators receive a request from the Smart City system. 2. This request could include • Heat supply • Electric absorption reduction • Green energy supply 3. The DC operator evaluates if the request can be accomplished 4. In the positive case the DC operator sends its response to the Smart City 5. In the negative case the DC operator shares the request with the other Data Centres of the federation 6. The DC federation evaluates the Smart City request and then the response is sent
Exceptions:	The Smart City request cannot be accomplished
Frequency of Use:	hourly, based on the Smart City dynamics
Assumptions:	• An advanced demand/response system should be implemented with the Smart City • The DC operator should have an automatic control system to interact with the Smart City control system
Risks:	
OPEX Analysis:	The overall energy cost of the Data Centres network is expected to be lowered. Direct impact from the Utility via special agreement to lower the peak load at specific time frames and avoid electricity network instability or even shell energy.

Table 5-22: Smart City (Synergetic DC /different administrative domains)

6. Use Cases Analysis using QFD

6.1. Quality Function Deployment - Introduction

The Quality Function Deployment (developed by Y. Akao in Japan in 1966) [50] is a systematic approach to design and develop a product (of any kind, including platforms/pieces of software) based on a close awareness of customer desires and requirements, coupled with the integration of functional groups (of a project team or company). Quoting Y. Akao, QFD "is a method for developing a design quality aimed at satisfying the consumer and then translating the consumer's demand into design targets and major quality assurance points to be used throughout the production phase. ... is a way to assure the **design quality while the product is still in the design stage**."

In essence, quality is the barycentre of the methodology and the ultimate goal is to translate (often) subjective quality criteria into objective ones that can be quantified and measured, and which can then be used to design and develop the product. Basically, QFD allows determining how and where priorities are to be assigned in product development a priori of implementation. The intent is to employ objective procedures in increasing detail throughout the development of the product or project.

The three main goals in implementing QFD are:

- Prioritize spoken and unspoken customer desires and needs;
- Translate these needs into technical characteristics, requirements and specifications;
- Develop and deliver a quality product (or service) by focusing on customer/user satisfaction whilst optimizing usage of internal costs, resources and teams (e.g. in a project, or in a Company).

Quality Function Deployment as depicted in Figure 6-1, uses some principles from Concurrent Engineering in that cross-functional teams are involved in all phases of product development. For further details see references [50] [51] . Each of the four phases in a QFD process uses a matrix to translate customer requirements from initial planning stages through production control. These phases are:

- ***Phase 1***: ***Product Planning***. It is also called The House of Quality. Main goals are: documenting customers' requirements, competitive opportunities, product measurements, competing product measures, and the technical ability of the organization to meet each customer requirement.
- ***Phase 2***: ***Product Design***. Product concepts are created during this phase and part specifications are documented. Parts that are determined to be most important to meeting customer needs are then deployed into process planning, or Phase 3.
- ***Phase 3: Process Planning***. During this phase, development processes are planned and flowcharted and the parameters (or target values) are documented.

- ***Phase 4: Process Control***. It concerns the control of the development processes, the maintenance of schedules, and skills training for developers. Also, in this phase decisions are made as to which process poses the most risk and controls are put in place to prevent failures.

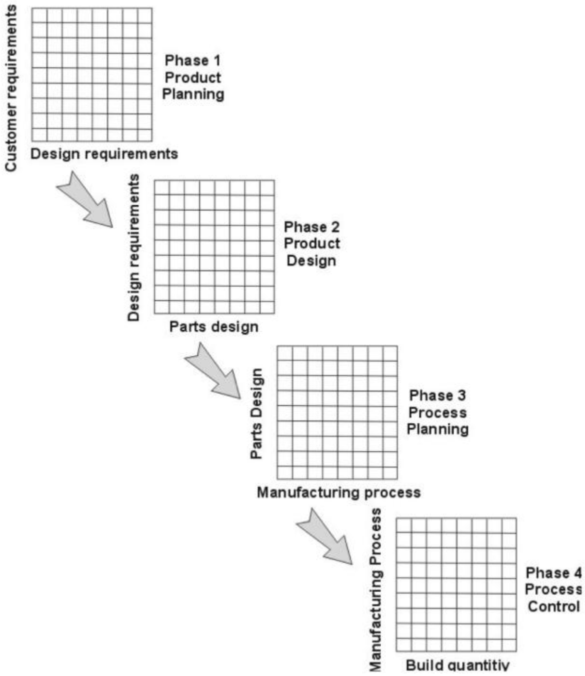

Figure 6-1: Flows of the QFD Analysis

In the context of DOLFIN we have applied the QFD analysis. More particularly, for each use-case in Dolfin project, we evaluated correlations between the business objectives /problems and the technology enablers and also between the business scenarios/problem and the technology enablers. In other words we evaluated how each technology enabler is contributing to solve each problem as a business objective / scenario objective.

The technology enables, business objectives and business scenarios used in the QFD analysis are as follows:

- ***Technology Enablers***: TE1.1-Dynamic Voltage Frequency Scaling (DVFS), TE1.2-Dynamic Power Management (DPM), TE1.3- Advanced Configuration and Power Interface (ACPI), TE2- Energy Aware Virtualization, TE3-Demand/Response Power Consumption, TE4- Energy-aware SLA Management, TE5.1- Migration of the operating infrastructure, TE5.2- Migration of ICT service data, TE5.3- Traffic redirection.

- ***Business Objectives:*** BO1.1- Reduce Server Costs, BO1.2- Reduce Infrastructure Costs, BO1.3- Reduce Power Costs, BO1.4- Reduce Other Costs, BO1.5- Reduce all operational costs, BO2- Increase the performance of offered services, BO3- Increase customer satisfaction, BO4- Improve the overall efficiency of the energy system, BO5.1-Shift processing power, BO5.2- Migrate processing power, BO6- Increase the availability /reliability of DC federation.

- ***Business Scenarios***: BS1- Energy efficient workload redistribution, BS2.1- Multi tariffs from the Utility companies, BS2.2- Flexible contract between the Utility, the Smart Grid and the DC owner, BS2.3- SLA Renegotiation with end customers, BS3.1- Multi tariffs from the Utility companies, BS3.2- Optimize benefits/incentives from national/European authorities, BS3.3- Smart City.

The use cases used in the QFD analysis are as follows:

- ***Use Cases:*** UC1 - Energy efficient workload redistribution, UC2 - Multi tariffs from the Utility companies, UC3 - Multi tariffs from the Utility companies, UC4- SLA Renegotiation with end customers, UC5 - Optimize benefits/incentives from national/European authorities, UC7 - Smart City

Correlation scores and importance factors for each problem were provided by an expert team from Interoute, Synelixis, Wind and GRNET. These correlation evaluations were done according to the following four Quality contexts for each UC problem/objective and technology enabler:

- ***Using a Single DC***: correlation values related to the system whose technology enablers are contributing to solve the problems (business objectives or scenarios) within a single Data Centre.
- ***Using a Synergetic DC of the same administrative domain***: correlation values related to the system whose technology enablers are contributing to solve the problems (business objectives or scenarios) within Synergetic Data Centres of the same administrative Domain.
- ***Using a Synergetic DC of different administrative domain**s*: correlation values related to the system whose technology enablers are contributing to solve the problems (business objectives or scenarios) within Synergetic Data Centres of alternative administrative Domain.
- ***Overall value***: correlation values related to the average of each previous value.

6.2. Results of QFD analysis

The results of the QFD analysis are in terms of ranked business objectives / scenario objectives emerging as important/less important for each use case as well as in terms of ranked technology enablers which are emerging to contribute most/least to the use case business objectives/ scenario objectives. These results will be used as input to the requirements elicited from each use case as well as the identifying priority requirements.

6.2.1. UC1 - Energy efficient workload redistribution

6.2.1.1. *Importance of UC1 business objectives when using the technology enablers*

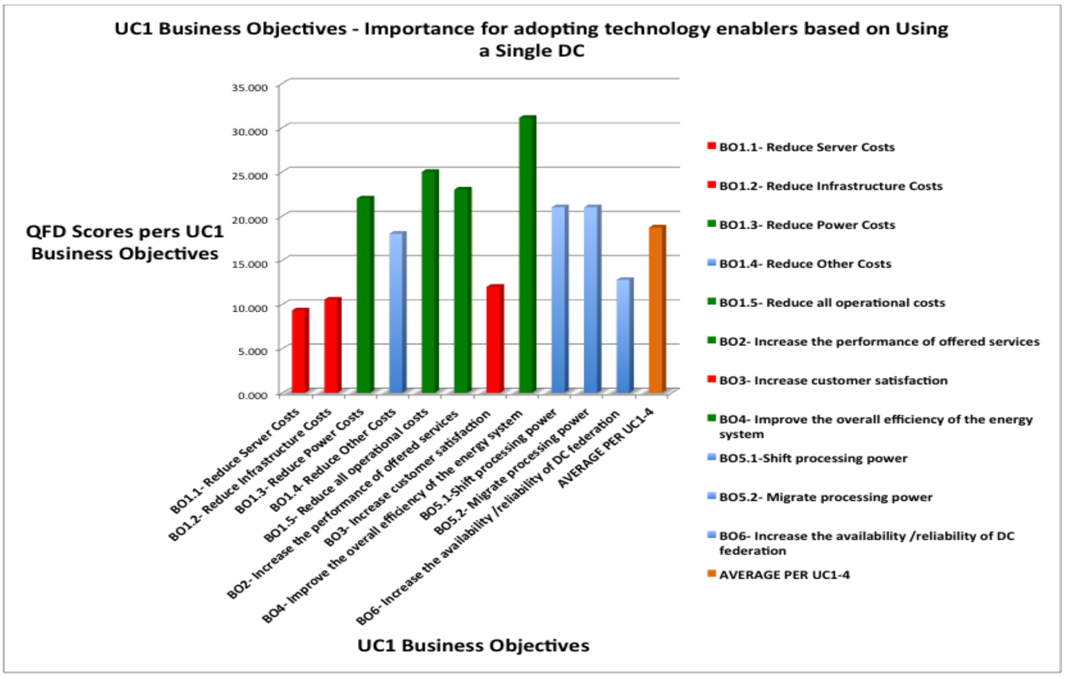

Figure 6-2: UC1 Business Objectives - Importance for adopting technology enablers (Single DC)

4 (of 11) business problems are emerging as very important to UC1:

- BO4- Improve the overall efficiency of the energy system
- BO1.5- Reduce all operational costs
- BO2- Increase the performance of offered services
- BO1.3- Reduce Power Costs

4 problems are following as important to UC1:

- BO5.1-Shift processing power
- BO5.2- Migrate processing power
- BO1.4- Reduce Other Costs
- BO6- Increase the availability /reliability of DC federation.

3 other business problems have a lower than average importance to UC1:

- BO1.1- Reduce Server Costs
- BO1.2- Reduce Infrastructure Costs
- BO3- Increase customer satisfaction

6.2.1.2. *Technology Enablers contribution to UC1 business objectives*

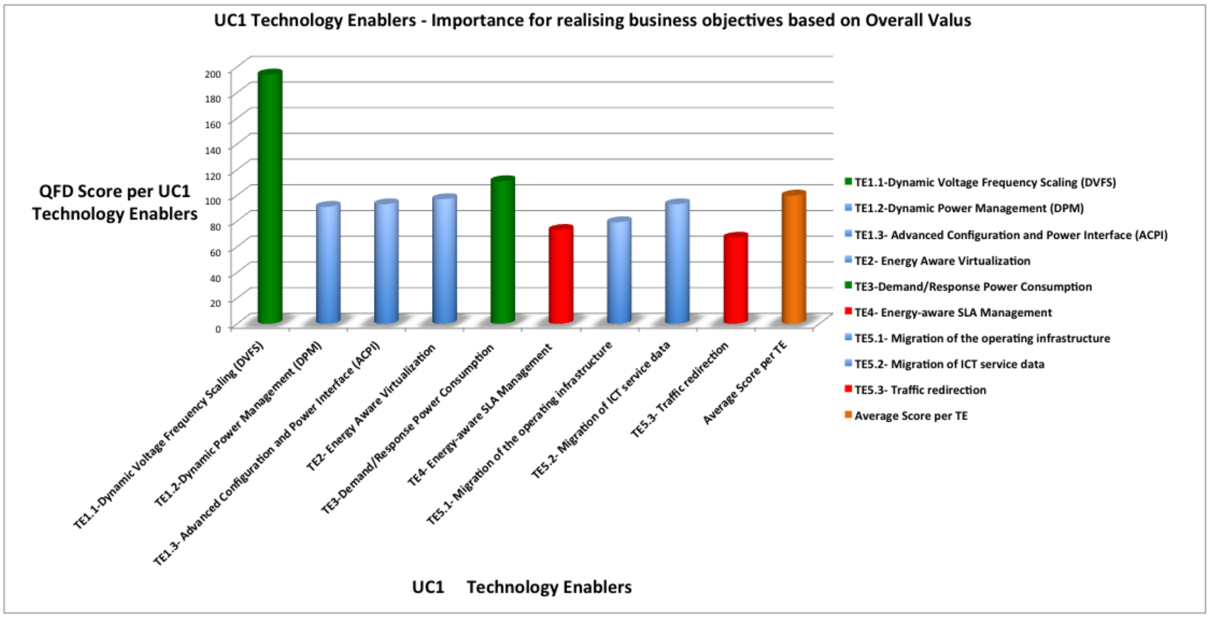

Figure 6-3: UC1 Technology Enablers - Importance for realising business objectives (Overall Value)

2 (of 9) technology enablers are emerging to contribute most to the UCL1 business objectives:

- TE1.1-Dynamic Voltage Frequency Scaling (DVFS)
- TE3-Demand/Response Power Consumption

5 technology enablers are following as contributors to UC1:

- TE1.2-Dynamic Power Management (DPM)
- TE1.3- Advanced Configuration and Power Interface (ACPI)
- TE2- Energy Aware Virtualization

- TE5.1- Migration of the operating infrastructure
- TE5.2- Migration of ICT service data

2 other technology enablers have a lower than average contribution to UC1:

- TE4- Energy-aware SLA Management
- TE5.3 - Traffic redirection

6.2.1.3. *Importance of scenario objectives within UC1 when using the technology enablers*

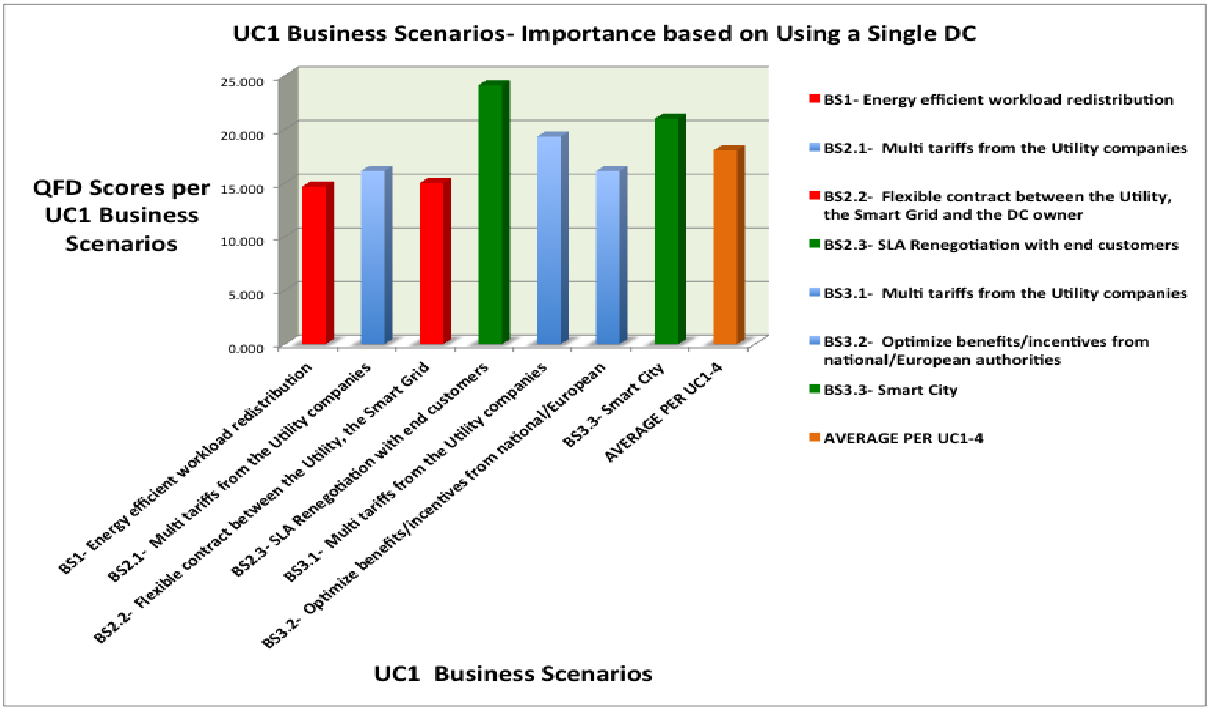

Figure 6-4: UC1 Business Scenarios- Importance in realising business scenarios (Single DC)

2 (of 7) business scenarios are emerging as very important for UC1:

- BS2.3- SLA Renegotiation with end customers
- BS3.3- Smart City

3 problems are following as important to UC1:

- BS2.1- Multi tariffs from the Utility companies
- BS3.1- Multi tariffs from the Utility companies
- BS3.2- Optimize benefits/incentives from national/European authorities,

2 other business problems have a lower than average importance to UC1:

- BS1- Energy efficient workload redistribution
- BS2.2- Flexible contract between the Utility, the Smart Grid and the DC owner

6.2.1.4. *Technology Enablers contribution to scenario objectives within UC1*

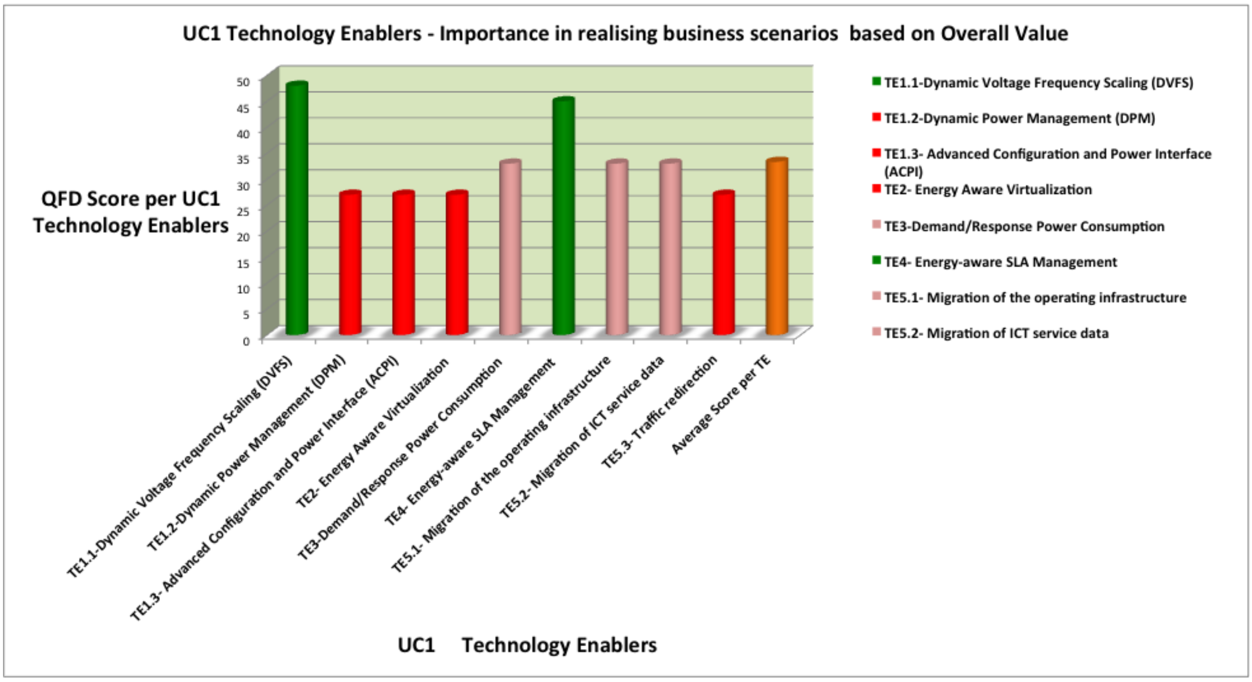

Figure 6-5: UC1 Technology Enablers - Importance in realising business scenarios (Overall Value)

2 (of 9) technology enablers are emerging to contribute most to the UC1 business scenarios:

- TE1.1-Dynamic Voltage Frequency Scaling (DVFS)
- TE4- Energy-aware SLA Management

3 technology enablers are following as contributors to UC1:

- TE3-Demand/Response Power Consumption
- TE5.1- Migration of the operating infrastructure
- TE5.2- Migration of ICT service data

4 other technology enablers have a lower than average contribution to UC1:

- TE1.2-Dynamic Power Management (DPM)
- TE1.3- Advanced Configuration and Power Interface (ACPI)
- TE2- Energy Aware Virtualization
- TE5.3 - Traffic redirection

6.2.2. UC2 - Multi tariffs from the Utility companies

6.2.2.1. *Importance of UC2 business objectives when using the technology enablers*

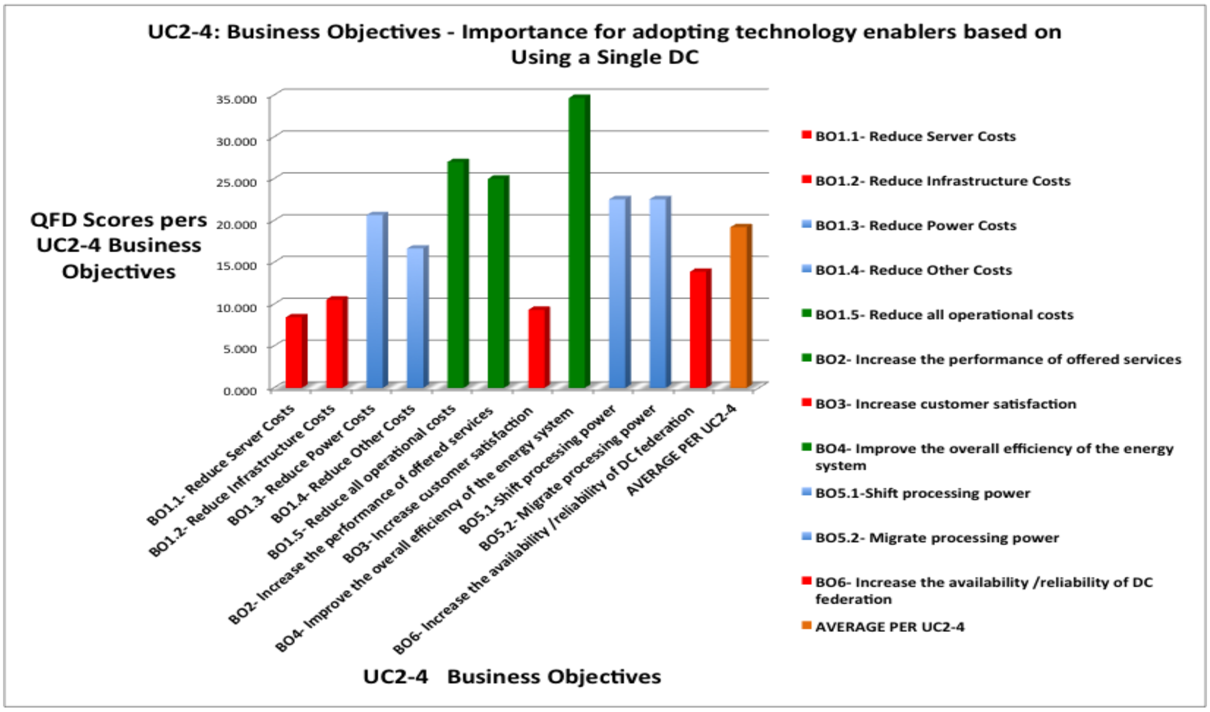

Figure 6-6: UC2 Business Objectives - Importance for adopting technology enablers (Single DC)

4 (of 11) business problems are emerging as very important for UC2:

- BO1.5- Reduce all operational costs
- BO2- Increase the performance of offered services
- BO4- Improve the overall efficiency of the energy system
- BO6- Increase the availability /reliability of DC federation

4 problems are following as important for UC2:

- BO1.3- Reduce Power Costs
- BO1.4- Reduce Other Costs
- BO5.1-Shift processing power
- BO5.2- Migrate processing power

3 other business problems have a lower than average importance for UC2:

- BO1.1- Reduce Server Costs
- BO1.2- Reduce Infrastructure Costs
- BO3- Increase customer satisfaction

6.2.2.2. *Technology Enablers contribution to UC2 business objectives*

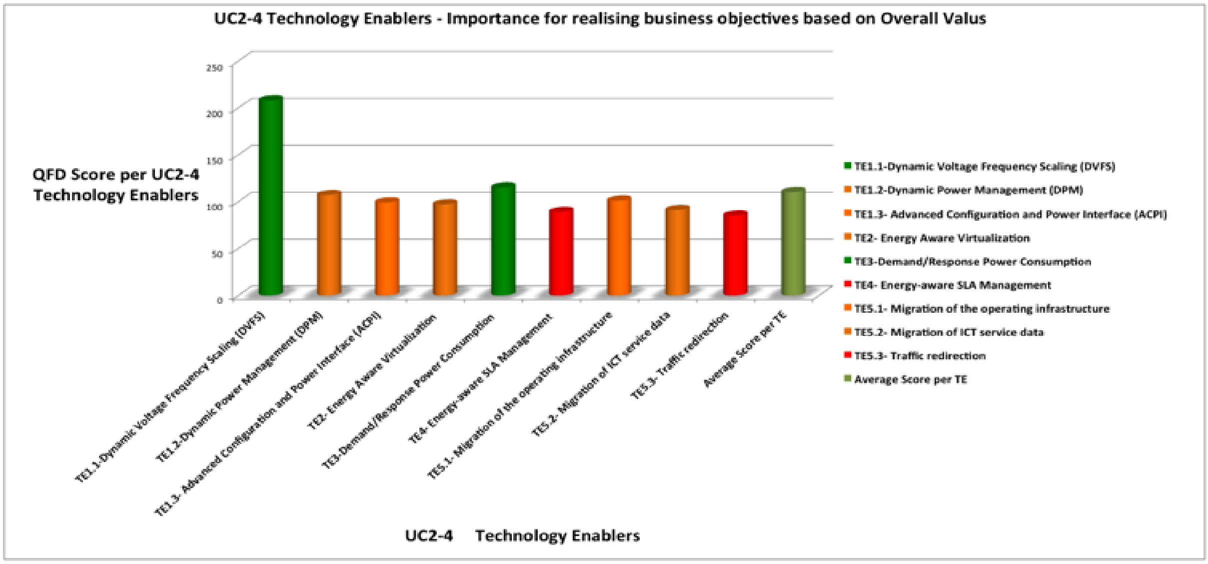

Figure 6-7: UC2 Technology Enablers - Importance for realising business objectives (Overall Value)

2 (of 9) technology enablers are emerging to contribute most to the UC2 business objectives:

- TE1.1-Dynamic Voltage Frequency Scaling (DVFS)
- TE3-Demand/Response Power Consumption

5 technology enablers are following as contributors for UC2:

- TE1.2-Dynamic Power Management (DPM)
- TE1.3- Advanced Configuration and Power Interface (ACPI)
- TE2- Energy Aware Virtualization
- TE5.1- Migration of the operating infrastructure
- TE5.2- Migration of ICT service data

2 other technology enablers have a lower than average contribution to UC2

- TE4- Energy-aware SLA Management
- TE5.3 - Traffic redirection

6.2.2.3. *Importance of scenario objectives within UC2 when using the technology enablers*

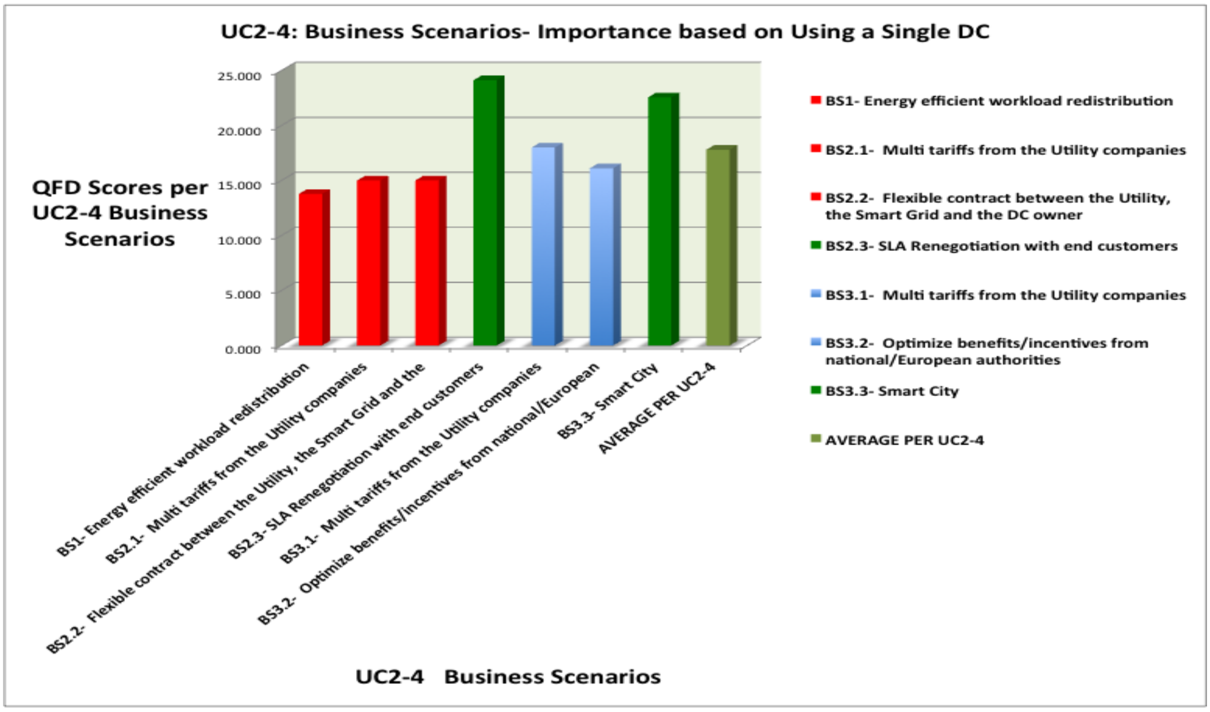

Figure 6-8: UC2 Business Scenarios- Importance in realising business scenarios (Single DC)

2 (of 7) business scenarios are emerging as very important for UC2:

- BS2.3- SLA Renegotiation with end customers
- BS3.3- Smart City

2 problems are following as important for UC2:

- BS3.1- Multi tariffs from the Utility companies
- BS3.2- Optimize benefits/incentives from national/European authorities

3 other business problems have a lower than average importance for UC2:

- BS1- Energy efficient workload redistribution
- BS2.1- Multi tariffs from the Utility companies
- BS2.2- Flexible contract between the Utility, the Smart Grid and the DC owner

6.2.2.4. *Technology Enablers contribution to scenario objectives within UC2*

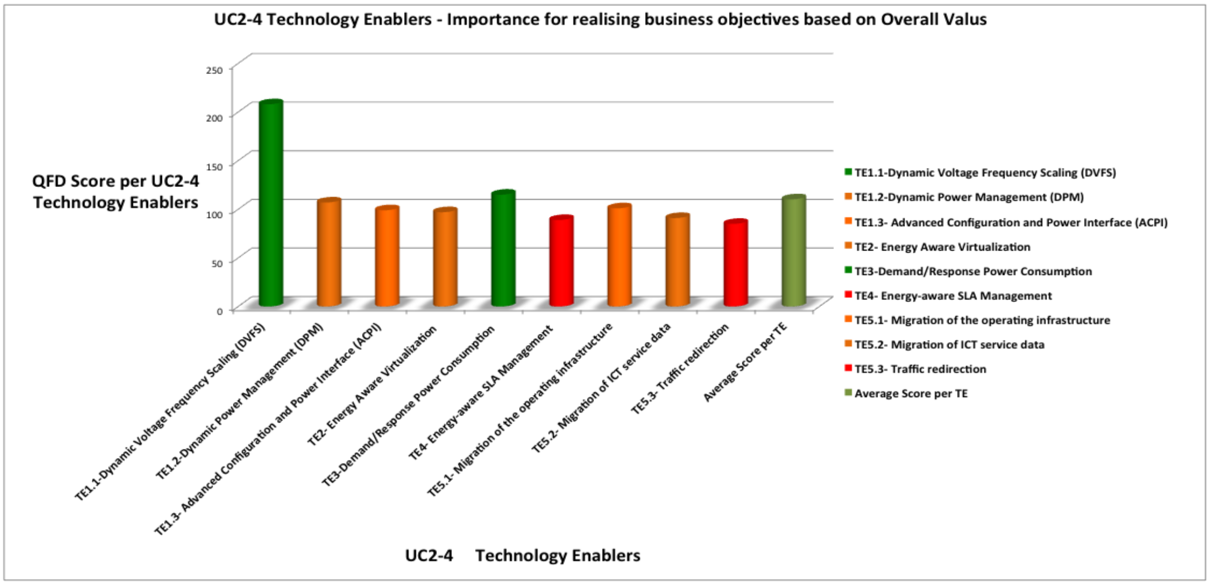

Figure 6-9: UC2 Technology Enablers - Importance in realising business scenarios (Overall Value)

2 (of 9) technology enablers are emerging to contribute most to the UC2 business scenarios:

- TE1.1-Dynamic Voltage Frequency Scaling (DVFS)
- TE3-Demand/Response Power Consumption

5 technology enablers are following as contributors for UC2:

- TE1.2-Dynamic Power Management (DPM)
- TE1.3- Advanced Configuration and Power Interface (ACPI)
- TE2- Energy Aware Virtualization
- TE5.1- Migration of the operating infrastructure
- TE5.2- Migration of ICT service data

2 other technology enablers have a lower than average contribution to UC2:

- TE4- Energy-aware SLA Management
- TE5.3 - Traffic redirection

6.2.3. UC3 - Multi tariffs from the Utility companies

6.2.3.1. *Importance of UC3 business objectives when using the technology enablers*

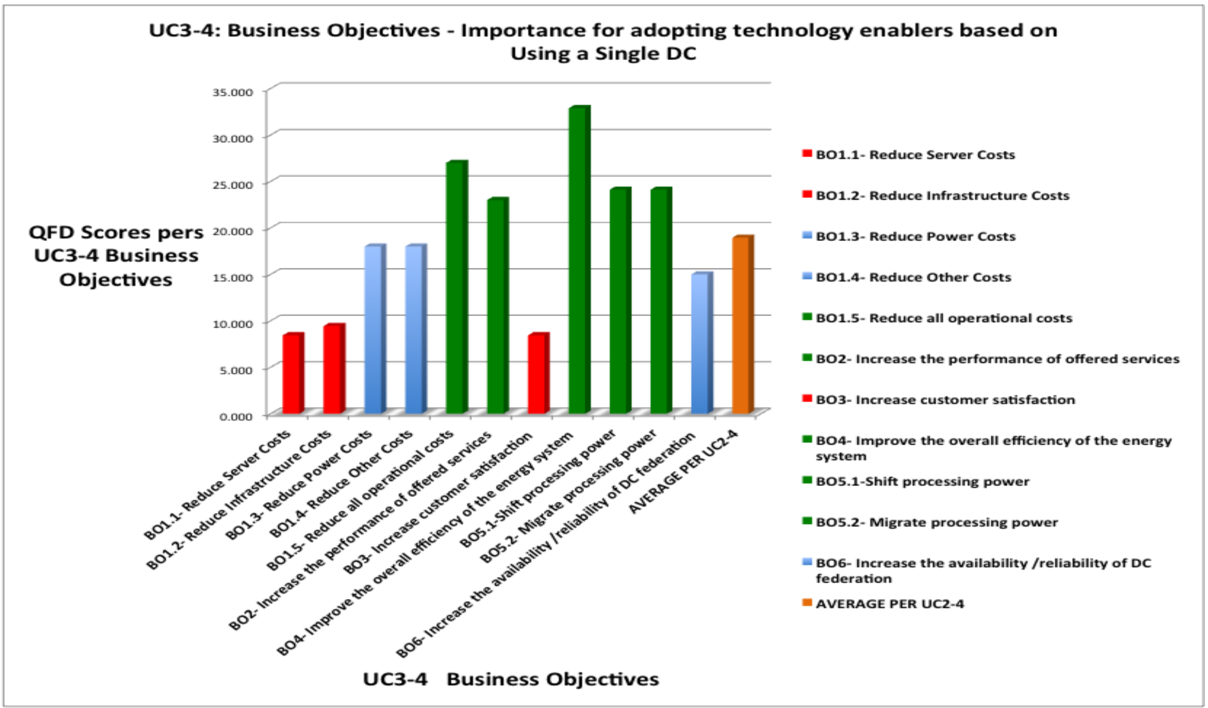

Figure 6-10: UC3 Business Objectives - Importance for adopting technology enablers (Single DC)

5 (of 11) business problems are emerging as very important to UC3:

- BO1.5- Reduce all operational costs
- BO2- Increase the performance of offered services
- BO4- Improve the overall efficiency of the energy system
- BO5.1-Shift processing power
- BO5.2- Migrate processing power

3 problems are following as important to UC3:

- BO1.3- Reduce Power Costs
- BO1.4- Reduce Other Costs
- BO6- Increase the availability /reliability of DC federation.

3 other business problems have a lower than average importance to UC3:

- BO1.1- Reduce Server Costs
- BO1.2- Reduce Infrastructure Costs
- BO3- Increase customer satisfaction

6.2.3.2. *Technology Enablers contribution to UC3 business objectives*

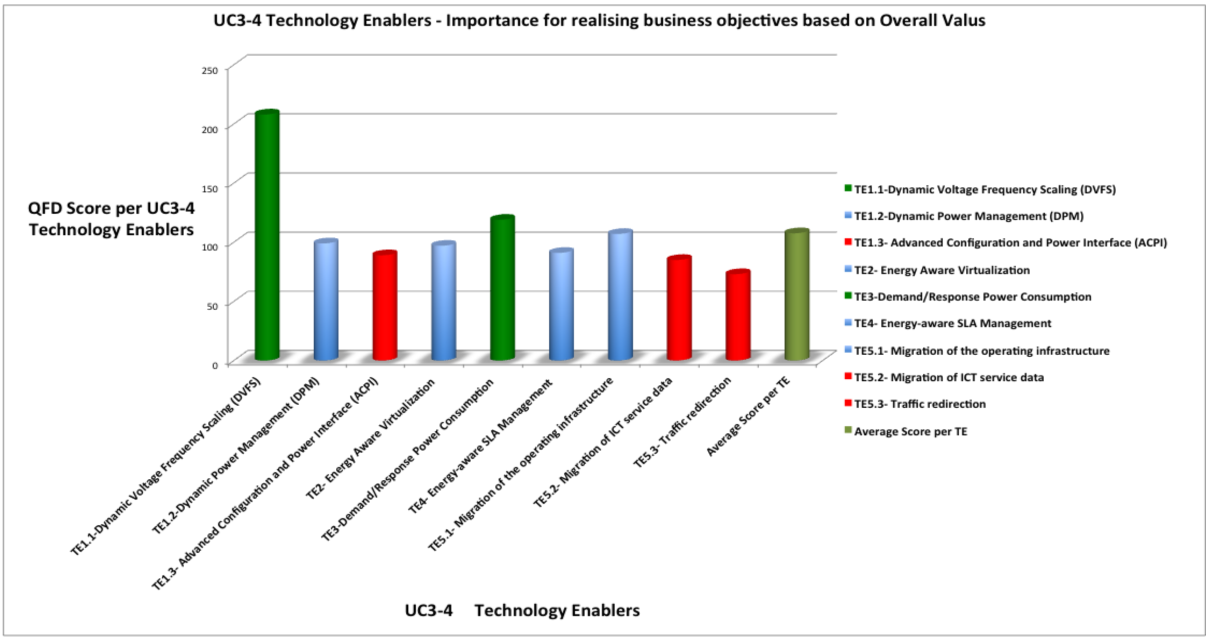

Figure 6-11: UC3 Technology Enablers - Importance for realising business objectives (Overall Value)

2 (of 9) technology enablers are emerging to contribute most to the UC3 business objectives:

- TE1.1-Dynamic Voltage Frequency Scaling (DVFS)
- TE3-Demand/Response Power Consumption

4 technology enablers are following as contributors to UC3:

- TE1.2-Dynamic Power Management (DPM)
- TE2- Energy Aware Virtualization
- TE4- Energy-aware SLA Management
- TE5.1- Migration of the operating infrastructure

3 other technology enablers have a lower than average contribution to UC3:

- TE1.3- Advanced Configuration and Power Interface (ACPI)
- TE5.2- Migration of ICT service data
- TE5.3 - Traffic redirection

6.2.3.3. *Importance of scenario objectives within UC3 when using the technology enablers*

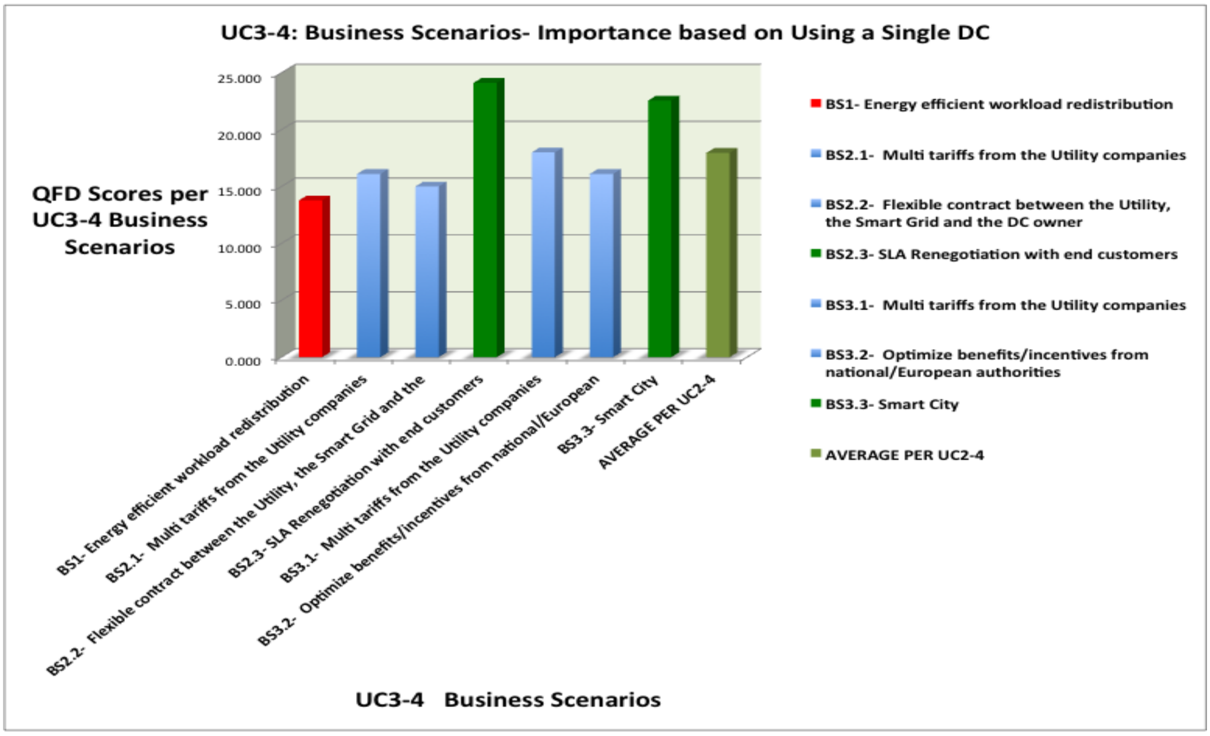

Figure 6-12: UC3 Business Scenarios- Importance in realising business scenarios (Single DC)

2 (of 7) business scenarios are emerging as very important to UC3:

- BS2.3- SLA Renegotiation with end customers
- BS3.3- Smart City

4 problems are following as important to UC3:

- BS2.1- Multi tariffs from the Utility companies
- BS2.2- Flexible contract between the Utility, the Smart Grid and the DC owner
- BS3.1- Multi tariffs from the Utility companies
- BS3.2- Optimize benefits/incentives from national/European authorities

1 other business problems have a lower than average importance to UC3:

- BS1- Energy efficient workload redistribution

6.2.3.4. *Technology Enablers contribution to scenario objectives within UC3*

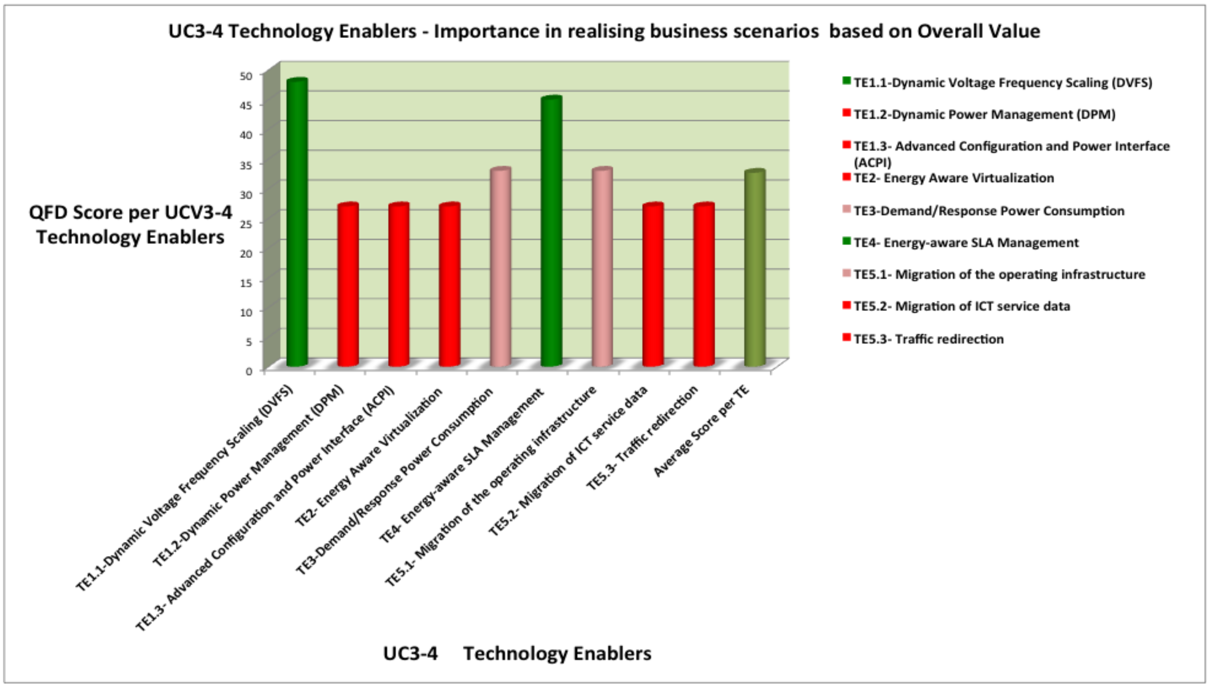

Figure 6-13: UC3 Technology Enablers - Importance in realising business scenarios (Overall Value)

2 (of 9) technology enablers are emerging to contribute most to the UC3 business scenarios:

- TE1.1-Dynamic Voltage Frequency Scaling (DVFS)
- TE4- Energy-aware SLA Management

2 technology enablers are following as contributors to UC3:

- TE3-Demand/Response Power Consumption
- TE5.1- Migration of the operating infrastructure

5 other technology enablers have a lower than average contribution to UC3:

- TE1.2-Dynamic Power Management (DPM)
- TE1.3- Advanced Configuration and Power Interface (ACPI)
- TE2- Energy Aware Virtualization
- TE5.2- Migration of ICT service data
- TE5.3 - Traffic redirection

6.2.4. UC4- SLA Renegotiation with end customers

6.2.4.1. *Importance of UC4 business objectives when using the technology enablers*

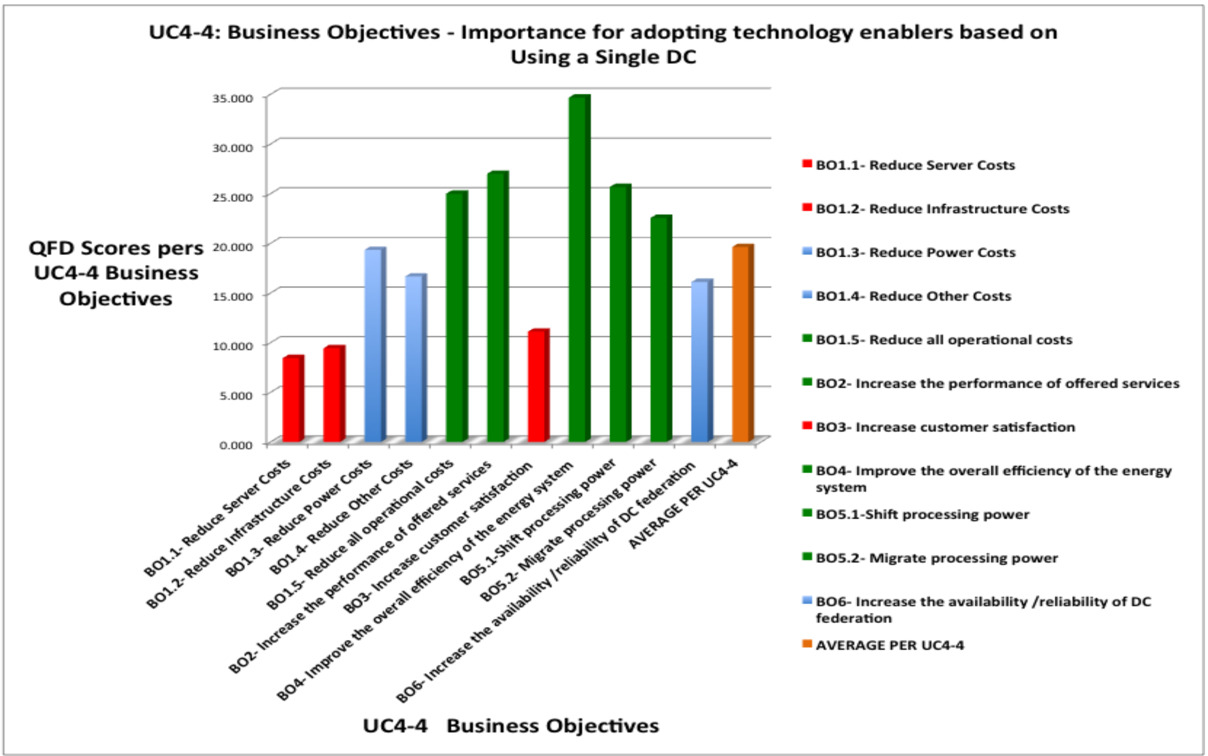

Figure 6-14: UC4 Business Objectives - Importance for adopting technology enablers (Single DC)

5 (of 11) business problems are emerging as very important to UC4:

- BO1.5- Reduce all operational costs
- BO2- Increase the performance of offered services
- BO4- Improve the overall efficiency of the energy system
- BO5.1-Shift processing power
- BO5.2- Migrate processing power

3 problems are following as important to UC4:

- BO1.3- Reduce Power Costs
- BO1.4- Reduce Other Costs
- BO6- Increase the availability /reliability of DC federation.

3 other business problems have a lower than average importance to UC4:

- BO1.1- Reduce Server Costs
- BO1.2- Reduce Infrastructure Costs
- BO3- Increase customer satisfaction

6.2.4.2. *Technology Enablers contribution to UC4 business objectives*

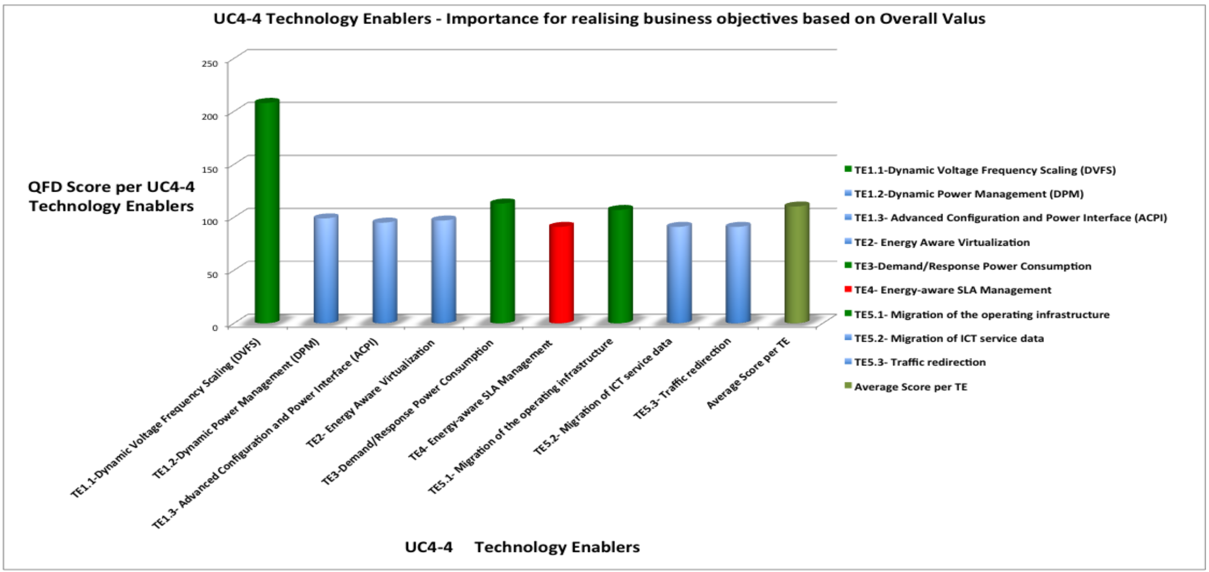

Figure 6-15: UC4 Technology Enablers - Importance for realising business objectives (Overall Value)

3 (of 9) technology enablers are emerging to contribute most to the UCL4 business objectives:

- TE1.1-Dynamic Voltage Frequency Scaling (DVFS)
- TE3-Demand/Response Power Consumption
- TE5.1- Migration of the operating infrastructure

5 technology enablers are following as contributors to UC4:

- TE1.2-Dynamic Power Management (DPM)
- TE1.3- Advanced Configuration and Power Interface (ACPI)
- TE2- Energy Aware Virtualization
- TE5.2- Migration of ICT service data
- TE5.3 - Traffic redirection

1 other technology enabler have a lower than average contribution to UC4:

- TE4- Energy-aware SLA Management

6.2.4.3. *Importance of scenario objectives within UC4 when using the technology enablers*

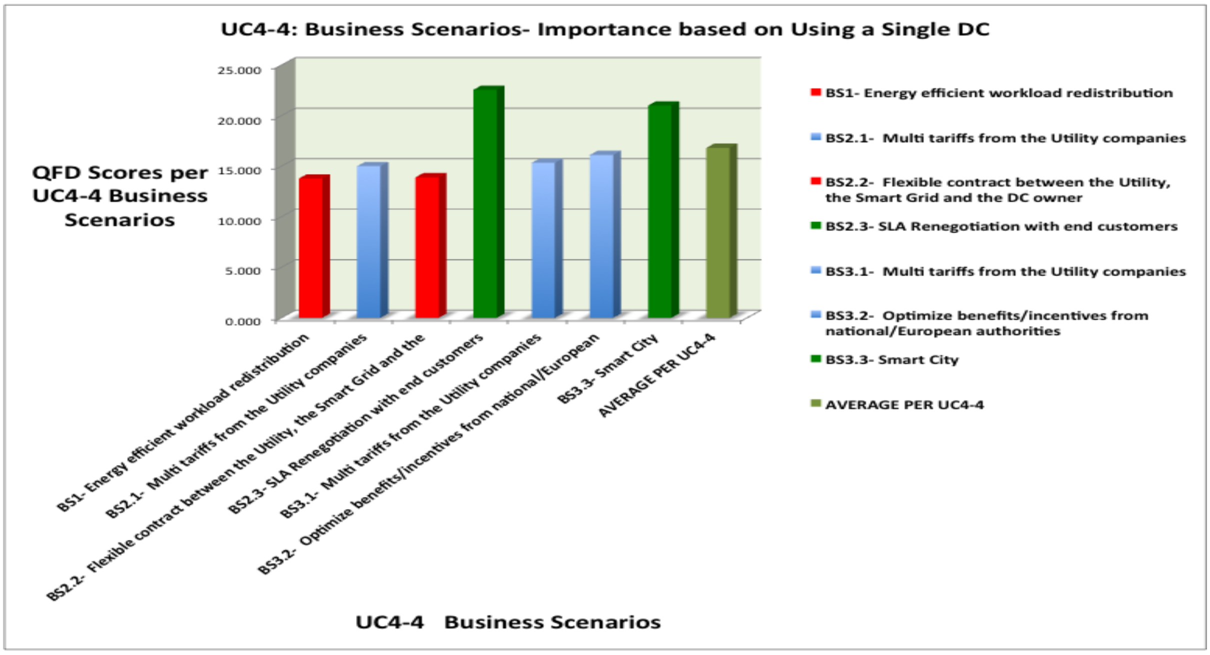

Figure 6-16: UC4 Business Scenarios- Importance realising business scenarios (Single DC)

2 (of 7) business scenarios are emerging as very important to UC4:

- BS2.3- SLA Renegotiation with end customers
- BS3.3- Smart City

3 problems are following as important to UC4:

- BS2.1- Multi tariffs from the Utility companies
- BS3.1- Multi tariffs from the Utility companies
- BS3.2- Optimize benefits/incentives from national/European authorities

2 other business problems have a lower than average importance to UC4:

- BS1- Energy efficient workload redistribution
- BS2.2- Flexible contract between the Utility, the Smart Grid and the DC owner

6.2.4.4. *Technology Enablers contribution to scenario objectives within UC4*

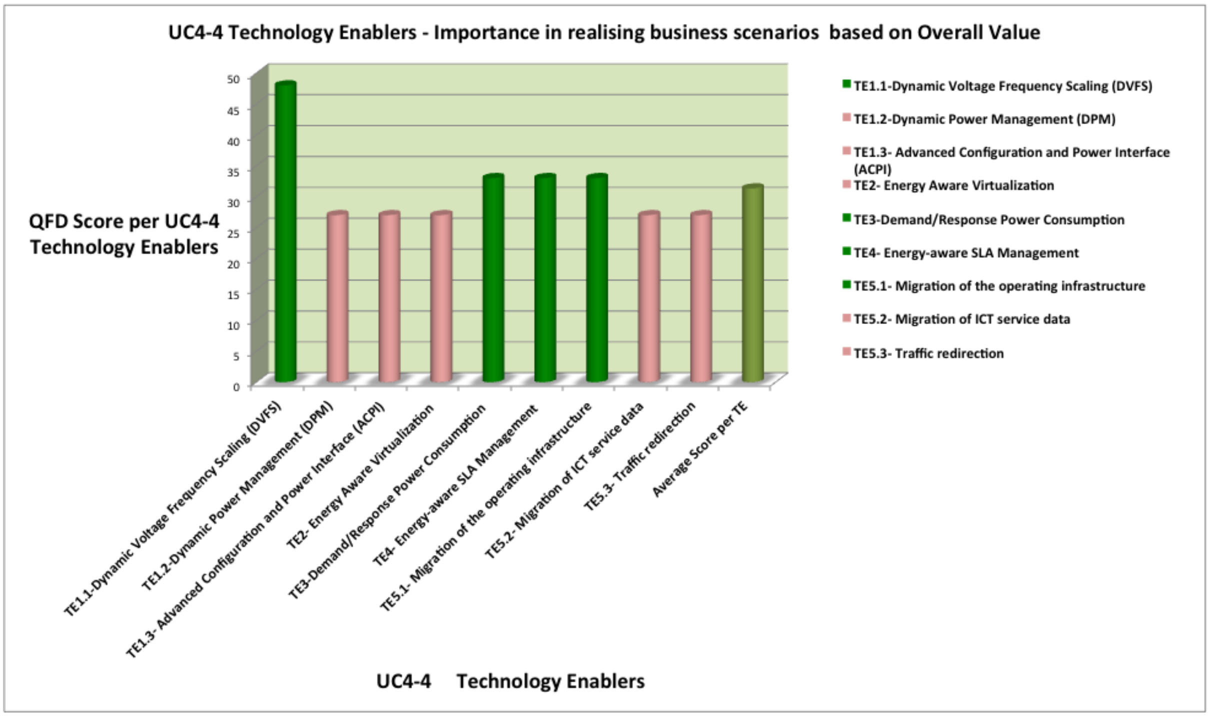

Figure 6-17: UC4 Technology Enablers - Importance in realising business scenarios (Overall Value)

4 (of 9) technology enablers are emerging to contribute most to the UC4 business scenarios:

- TE1.1-Dynamic Voltage Frequency Scaling (DVFS)
- TE3-Demand/Response Power Consumption
- TE4- Energy-aware SLA Management
- TE5.1- Migration of the operating infrastructure

5 technology enablers are following as contributors to UC4:

- TE1.2-Dynamic Power Management (DPM)
- TE1.3- Advanced Configuration and Power Interface (ACPI)
- TE2- Energy Aware Virtualization
- TE5.2- Migration of ICT service data
- TE5.3 - Traffic redirection

6.2.5. UC5 -Green-powered service to end customers

6.2.5.1. *Importance of UC5 business objectives when using the technology enablers*

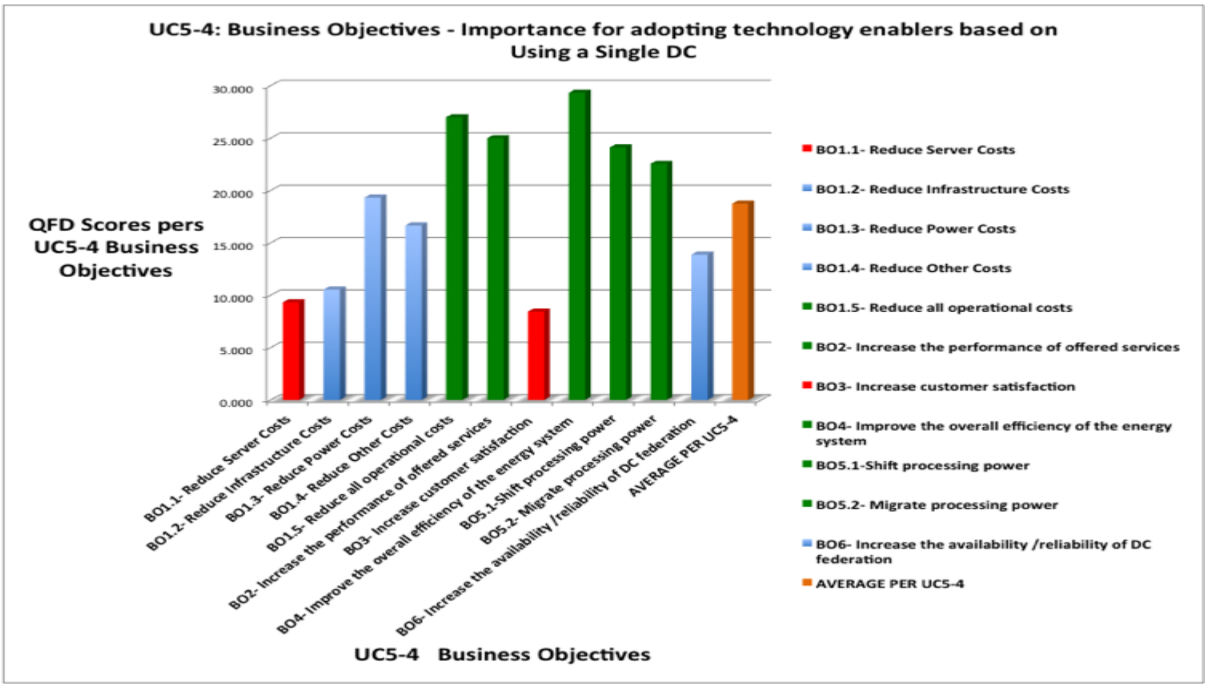

Figure 6-18: UC5 Business Objectives - Importance for adopting technology enablers (Single DC)

5 (of 11) business problems are emerging as very important to UC5:

- BO1.5- Reduce all operational costs
- BO2- Increase the performance of offered services
- BO4- Improve the overall efficiency of the energy system
- BO5.1-Shift processing power
- BO5.2- Migrate processing power

4 problems are following as important to UC5:

- BO1.2- Reduce Infrastructure Costs
- BO1.3- Reduce Power Costs
- BO1.4- Reduce Other Costs
- BO6- Increase the availability /reliability of DC federation.

2 other business problems have a lower than average importance to UC5:

- BO1.1- Reduce Server Costs
- BO3- Increase customer satisfaction

6.2.5.2. *Technology Enablers contribution to UC5 business objectives*

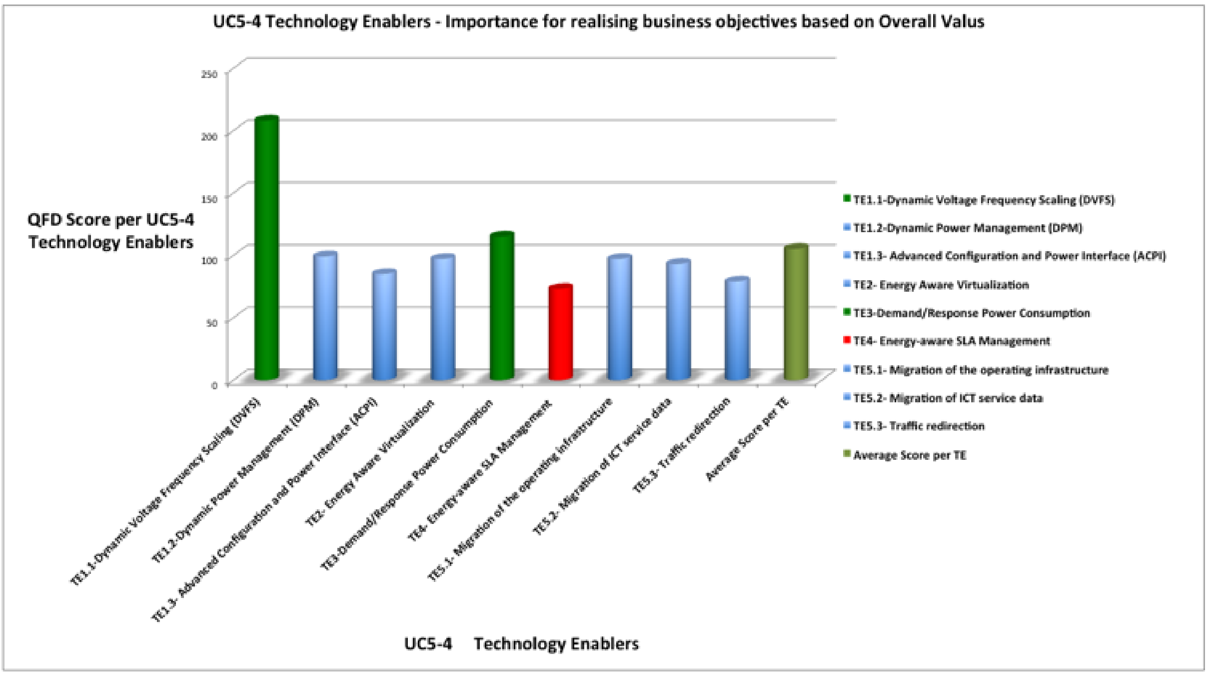

Figure 6-19: UC5 Technology Enablers - Importance for realising business objectives (Overall Value)

2 (of 9) technology enablers are emerging to contribute most to the UC5 business objectives:

- TE1.1-Dynamic Voltage Frequency Scaling (DVFS)
- TE3-Demand/Response Power Consumption

6 technology enablers are following as contributors to UC5:

- TE1.2-Dynamic Power Management (DPM)
- TE1.3- Advanced Configuration and Power Interface (ACPI)
- TE2- Energy Aware Virtualization
- TE5.1- Migration of the operating infrastructure
- TE5.2- Migration of ICT service data
- TE5.3 - Traffic redirection

1 other technology enabler have a lower than average contribution to UC5:

- TE4- Energy-aware SLA Management

6.2.5.3. *Importance of scenario objectives within UC5 when using the technology enablers*

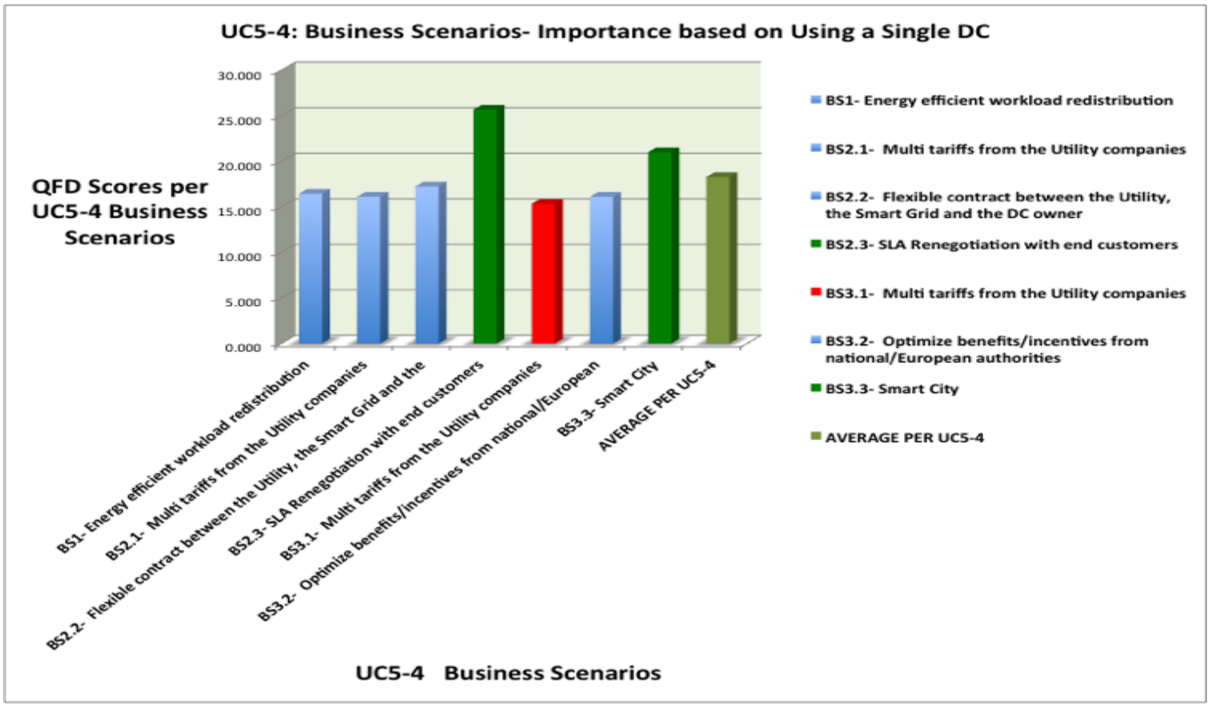

Figure 6-20: UC5 Business Scenarios- Importance (Single DC)

2 (of 7) business scenarios are emerging as very important to UC5:

- BS2.3- SLA Renegotiation with end customers
- BS3.3- Smart City

4 problems are following as important to UC5:

- BS1- Energy efficient workload redistribution
- BS2.1- Multi tariffs from the Utility companies
- BS2.2- Flexible contract between the Utility, the Smart Grid and the DC owner
- BS3.2- Optimize benefits/incentives from national/European authorities

1 other business problem1 have a lower than average importance to UC5:

- BS3.1- Multi tariffs from the Utility companies

6.2.5.4. *Technology Enablers contribution to scenario objectives within UC5*

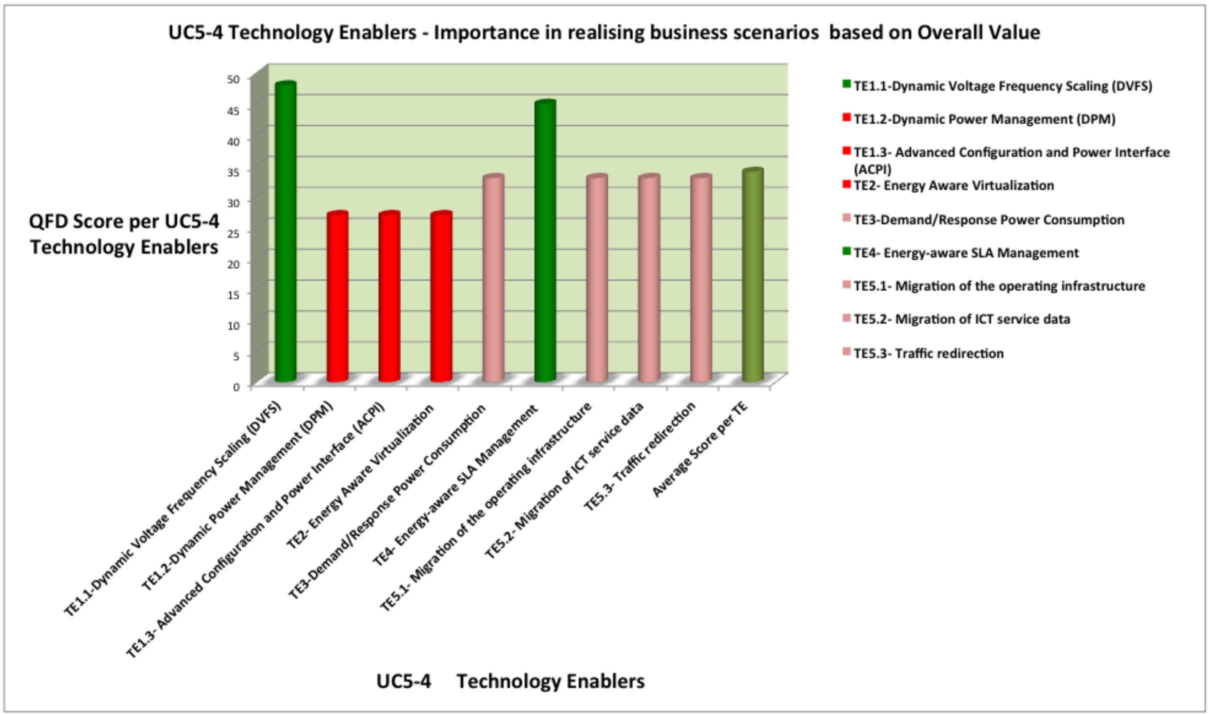

Figure 6-21: UC5 Technology Enablers - Importance in realising business scenarios (Overall Value)

2 (of 9) technology enablers are emerging to contribute most to the UC5 business scenarios:

- TE1.1-Dynamic Voltage Frequency Scaling (DVFS)
- TE4- Energy-aware SLA Management

4 technology enablers are following as contributors to UC5:

- TE3-Demand/Response Power Consumption
- TE5.1- Migration of the operating infrastructure
- TE5.2- Migration of ICT service data
- TE5.3 - Traffic redirection

3 other technology enablers have a lower than average contribution to UC5:

- TE1.2-Dynamic Power Management (DPM)
- TE1.3- Advanced Configuration and Power Interface (ACPI)
- TE2- Energy Aware Virtualization

6.2.6. UC6- Optimize benefits/incentives from national/European authorities

6.2.6.1. *Importance of UC6 business objectives when using the technology enablers*

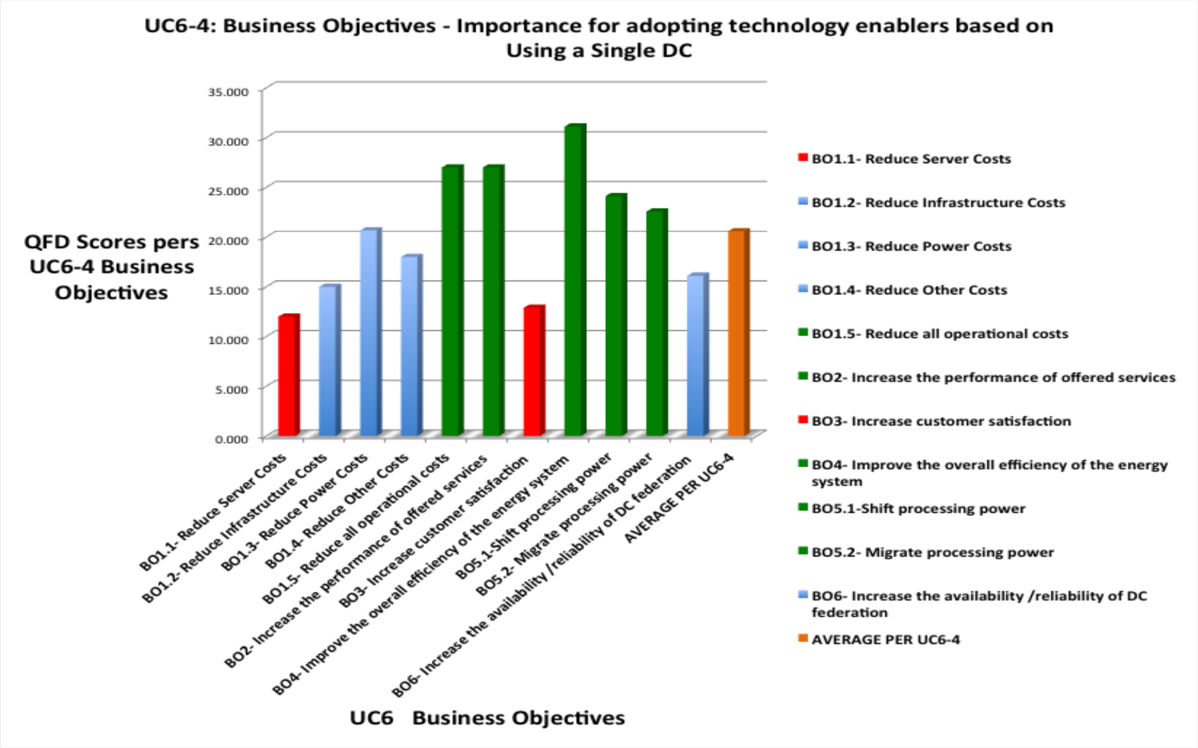

Figure 6-22: UC6 Business Objectives - Importance for adopting technology enablers (Single DC)

5 (of 11) business problems are emerging as very important to UC6:

- BO1.5- Reduce all operational costs
- BO2- Increase the performance of offered services
- BO4- Improve the overall efficiency of the energy system
- BO5.1-Shift processing power
- BO5.2- Migrate processing power

4 problems are following as important to UC6:

- BO1.2- Reduce Infrastructure Costs
- BO1.3- Reduce Power Costs
- BO1.4- Reduce Other Costs
- BO6- Increase the availability /reliability of DC federation.

2 other business problems have a lower than average importance to UC6:

- BO1.1- Reduce Server Costs
- BO3- Increase customer satisfaction

6.2.6.2. *Technology Enablers contribution to UC6 business objectives*

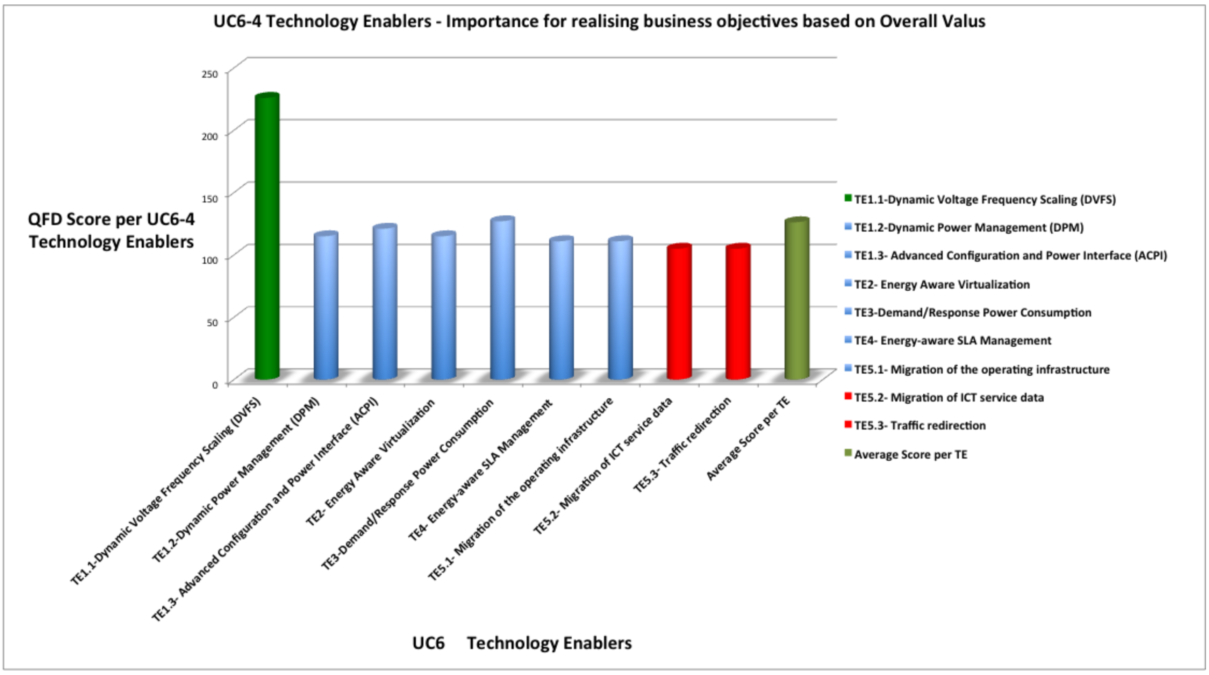

Figure 6-23: UC6 Technology Enablers - Importance for realising business objectives (Overall Value)

1 (of 9) technology enabler is emerging to contribute most to the UC6 business objectives:

- TE1.1-Dynamic Voltage Frequency Scaling (DVFS)

6 technology enablers are following as contributors to UC6:

- TE1.2-Dynamic Power Management (DPM)
- TE1.3- Advanced Configuration and Power Interface (ACPI)
- TE2- Energy Aware Virtualization
- TE3-Demand/Response Power Consumption
- TE4- Energy-aware SLA Management
- TE5.1- Migration of the operating infrastructure

2 other technology enablers have a lower than average contribution to UC6:

- TE5.2- Migration of ICT service data
- TE5.3 - Traffic redirection

6.2.6.3. *Importance of scenario objectives within UC6 when using the technology enablers*

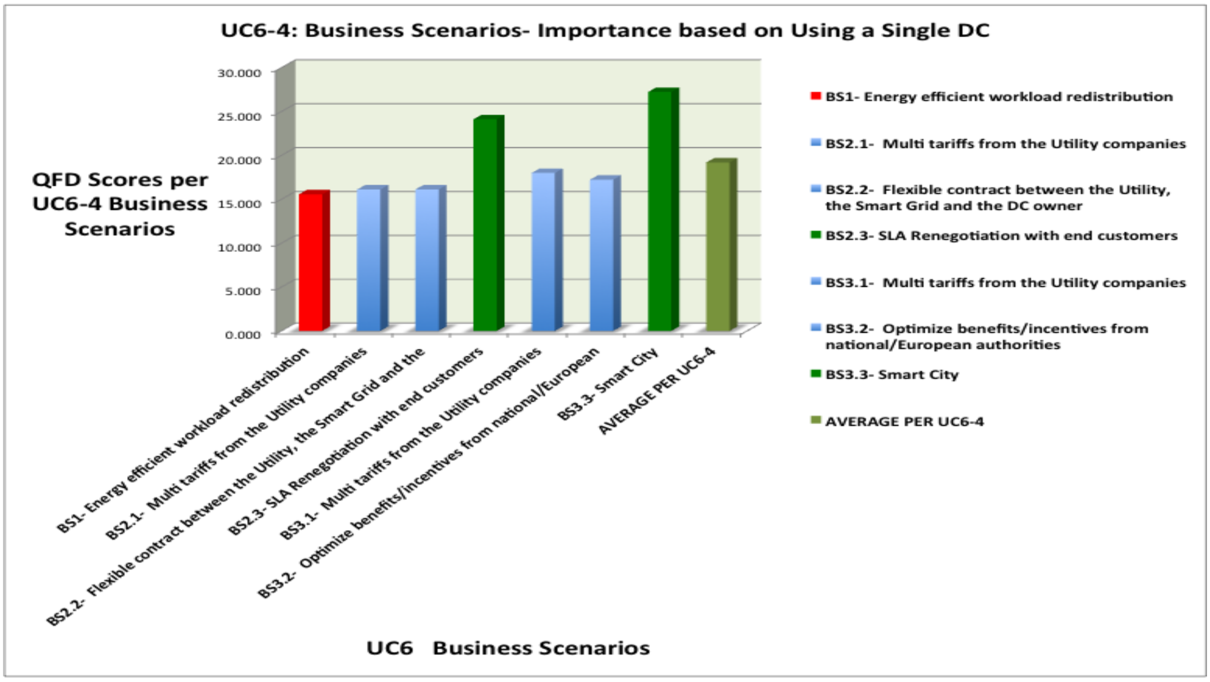

Figure 6-24: UC6 Business Scenarios- Importance (Single DC)

2 (of 7) business scenarios are emerging as very important:

- BS2.3- SLA Renegotiation with end customers
- BS3.3- Smart City

4 problems are following as important:

- BS2.1- Multi tariffs from the Utility companies
- BS2.2- Flexible contract between the Utility, the Smart Grid and the DC owner
- BS3.1- Multi tariffs from the Utility companies
- BS3.2- Optimize benefits/incentives from national/European authorities

1 other business problem have a lower than average importance

- BS1- Energy efficient workload redistribution

6.2.6.4. *Technology Enablers contribution to scenario objectives within UC6*

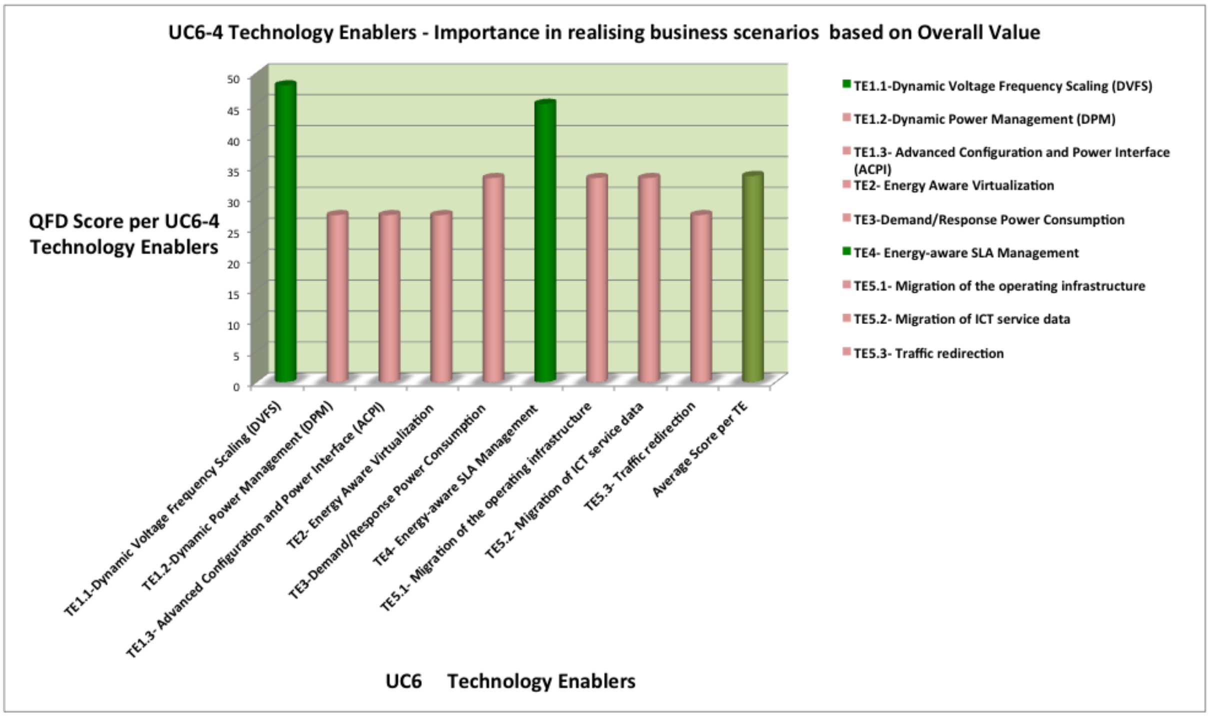

Figure 6-25: UC6 Technology Enablers - Importance in realising business scenarios (Overall Value)

2 (of 9) technology enablers are emerging to contribute most to the UC6 business scenarios:

- TE1.1-Dynamic Voltage Frequency Scaling (DVFS)
- TE4- Energy-aware SLA Management

7 technology enablers are following as contributors to UC6:

- TE1.2-Dynamic Power Management (DPM)
- TE1.3- Advanced Configuration and Power Interface (ACPI)
- TE2- Energy Aware Virtualization
- TE3-Demand/Response Power Consumption
- TE5.1- Migration of the operating infrastructure
- TE5.2- Migration of ICT service data
- TE5.3 - Traffic redirection

6.2.7. UC7 - Smart City

6.2.7.1. *Importance of UC7 business objectives when using the technology enablers*

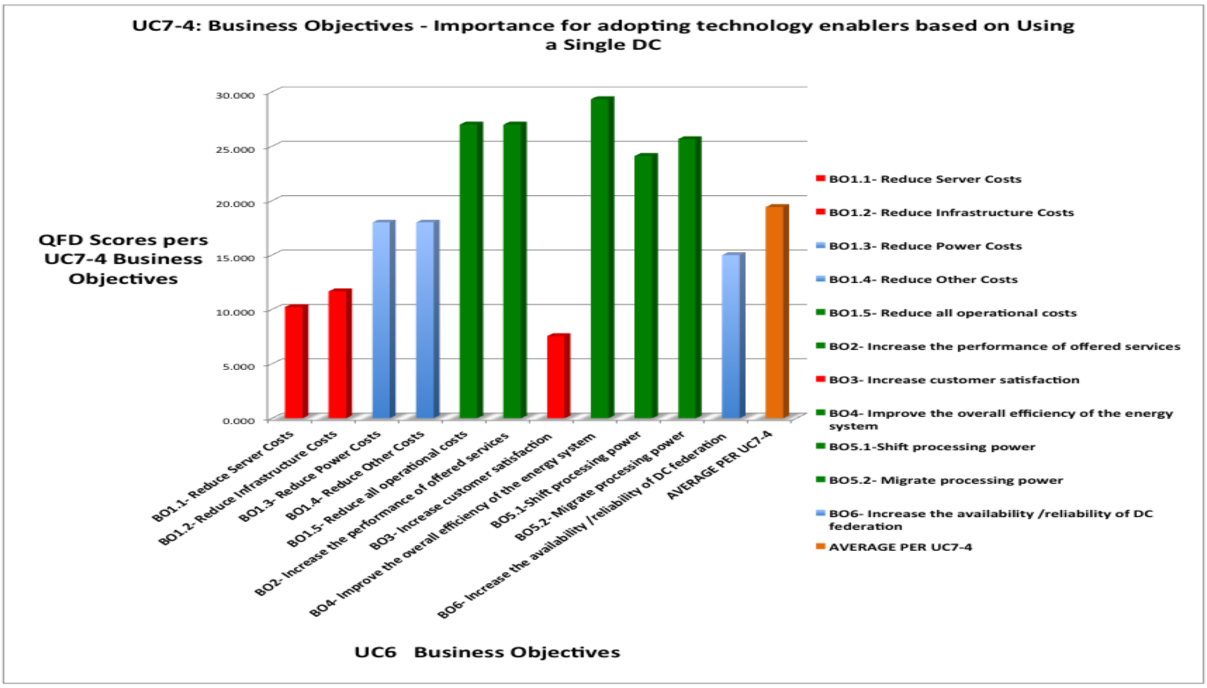

Figure 6-26: UC7 Business Objectives - Importance for adopting technology enablers (Single DC)

5 (of 11) business problems are emerging as very important to UC7:

- BO1.5- Reduce all operational costs
- BO2- Increase the performance of offered services
- BO4- Improve the overall efficiency of the energy system
- BO5.1-Shift processing power
- BO5.2- Migrate processing power

3 problems are following as important to UC7:

- BO1.3- Reduce Power Costs
- BO1.4- Reduce Other Costs
- BO6- Increase the availability /reliability of DC federation.

3 other business problems have a lower than average importance to UC7:

- BO1.1- Reduce Server Costs
- BO1.2- Reduce Infrastructure Costs
- BO3- Increase customer satisfaction

6.2.7.2. *Technology Enablers contribution to UC7 business objectives*

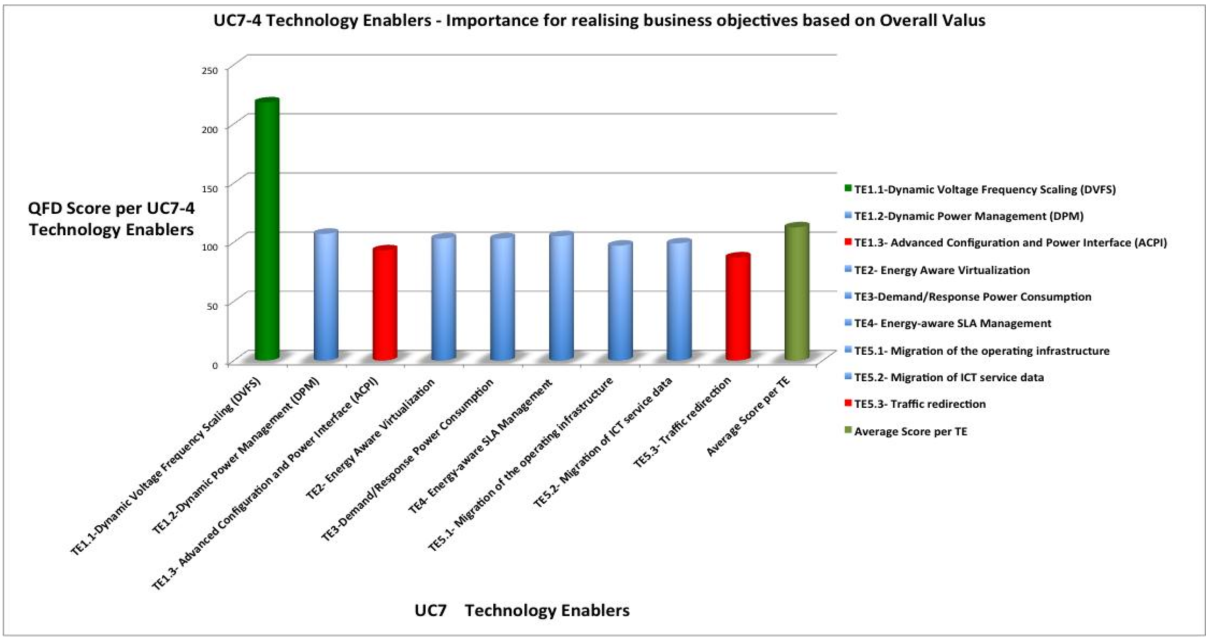

Figure 6-27: UC7 Technology Enablers - Importance for realising business objectives (Overall Value)

1 (of 9) technology enabler is emerging to contribute most to the UC7 business objectives:

- TE1.1-Dynamic Voltage Frequency Scaling (DVFS)

6 technology enablers are following as contributors to UC7:

- TE1.2-Dynamic Power Management (DPM)
- TE2- Energy Aware Virtualization
- TE3-Demand/Response Power Consumption
- TE4- Energy-aware SLA Management
- TE5.1- Migration of the operating infrastructure
- TE5.2- Migration of ICT service data

2 other technology enablers have a lower than average contribution to UC7:

- TE1.3- Advanced Configuration and Power Interface (ACPI)
- TE5.3 - Traffic redirection

6.2.7.3. *Importance of scenario objectives within UC7 when using the technology enablers*

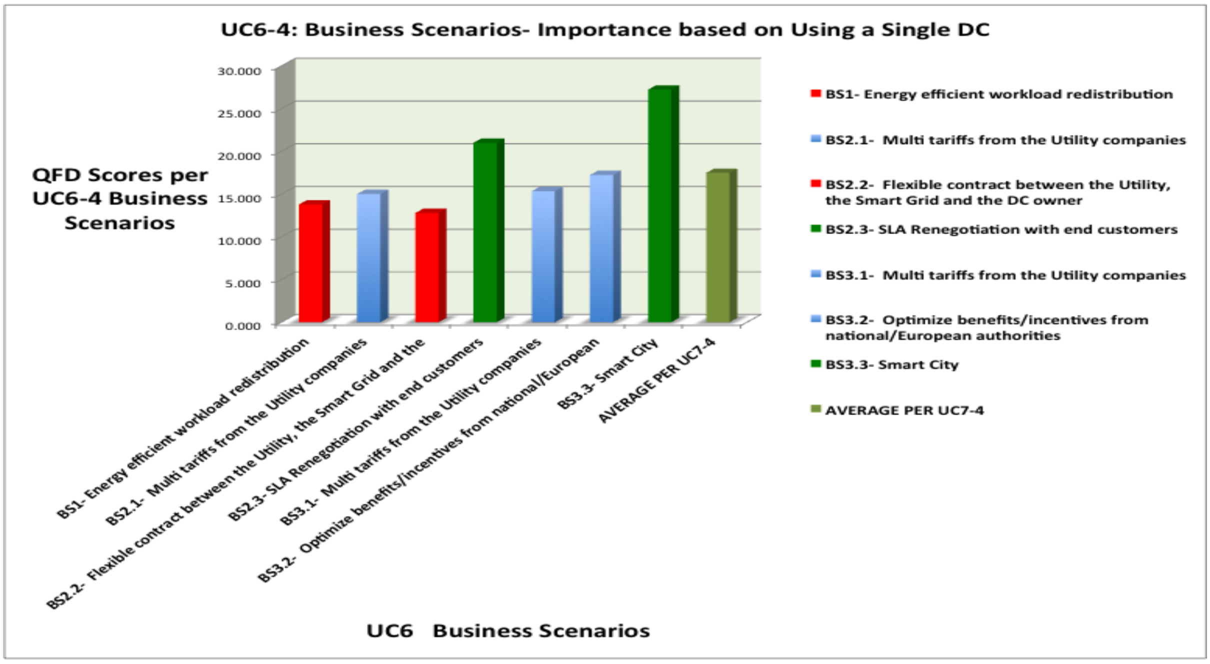

Figure 6-28: UC7 Business Scenarios- Importance (Single DC)

2 (of 7) business scenarios are emerging as very important:

- BS2.3- SLA Renegotiation with end customers
- BS3.3- Smart City

3 problems are following as important:

- BS2.1- Multi tariffs from the Utility companies
- BS3.1- Multi tariffs from the Utility companies
- BS3.2- Optimize benefits/incentives from national/European authorities

2 other business problems have a lower than average importance

- BS1- Energy efficient workload redistribution
- BS2.2- Flexible contract between the Utility, the Smart Grid and the DC owner

6.2.7.4. *Technology Enablers contribution to scenario objectives within UC7*

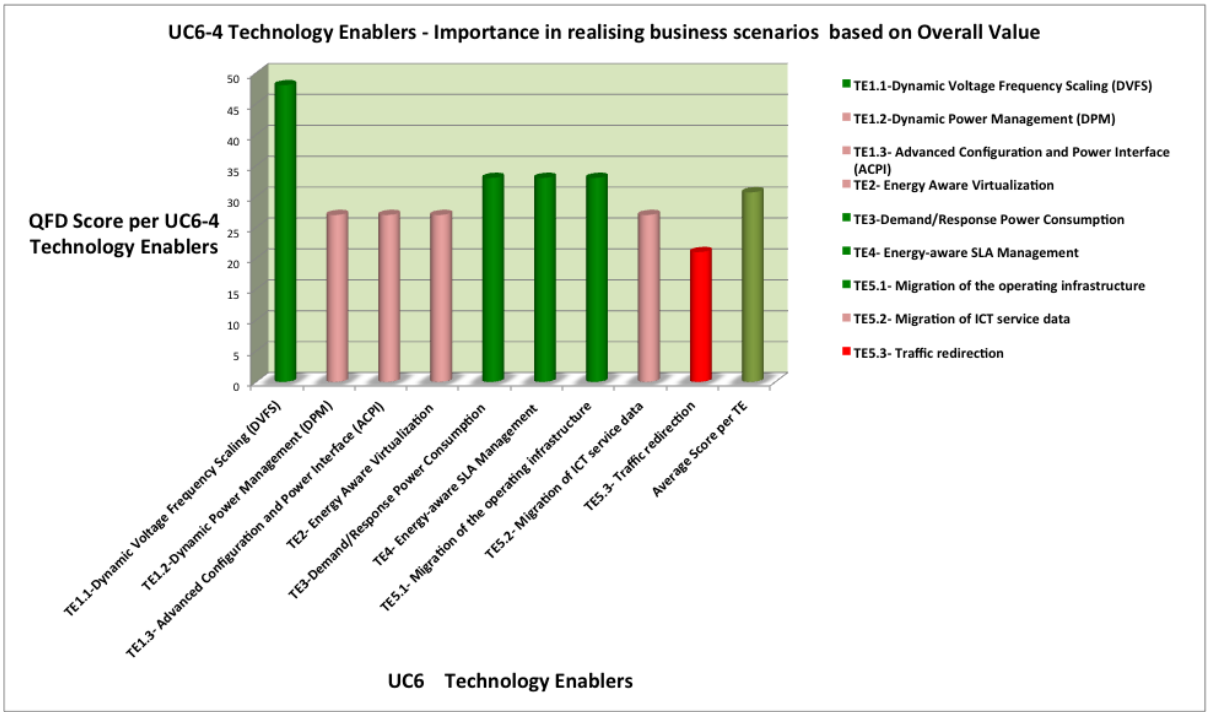

Figure 6-29: UC7 Technology Enablers - Importance in realising business scenarios (Overall Value)

4 (of 9) technology enablers are emerging to contribute most to the UC7 business scenarios:

- TE1.1-Dynamic Voltage Frequency Scaling (DVFS)
- TE3-Demand/Response Power Consumption
- TE4- Energy-aware SLA Management
- TE5.1- Migration of the operating infrastructure

4 technology enablers are following as contributors to UC7:

- TE1.2-Dynamic Power Management (DPM)
- TE1.3- Advanced Configuration and Power Interface (ACPI)
- TE2- Energy Aware Virtualization
- TE5.2- Migration of ICT service data

1 other technology enabler has a lower than average contribution to UC7:

- TE5.3 - Traffic redirection

6.3. Use Cases Prioritisation using QFD Analysis

Wrapping up the conducted QFD analysis, the rest of this section summarizes the respective results regarding the evaluation of both the business objectives and the business scenarios in hand. Specifically, a prioritization of the various use cases per business objective and scenario is attempted. Finally, for each of the two business aspects examined, an overall value analysis is presented, indicative of the design quality of the project as a whole.

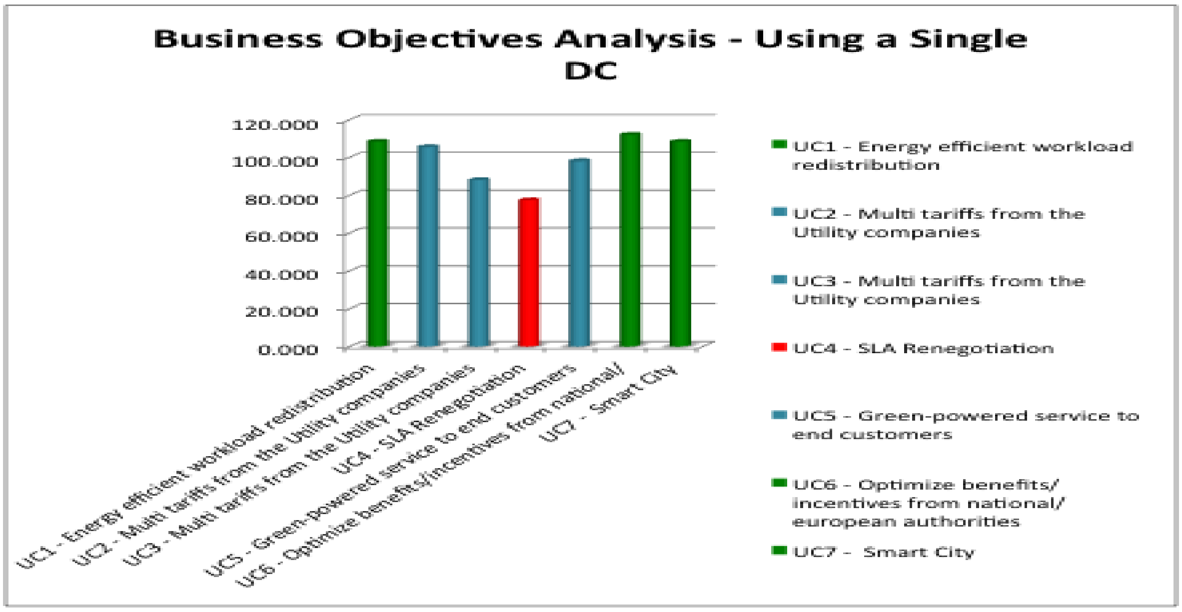

Figure 6-30: Business Objectives Analysis (Data Centre)

3 (of 7) use cases are emerging to contribute most to the business objectives when using a single data centre:

- UC1 - Energy efficient workload redistribution
- UC6 - Optimize benefits/incentives from national/European authorities
- UC7 - Smart City

3 use cases are following as contributors to the business objectives when using a single data centre:

- UC2 - Multi tariffs from the Utility companies
- UC3 - Multi tariffs from the Utility companies
- UC5 - Green-powered service to end customers

1 other use case has a lower than average contribution to the business objectives when using a single data centre:

- UC4 - SLA Renegotiation with end customers

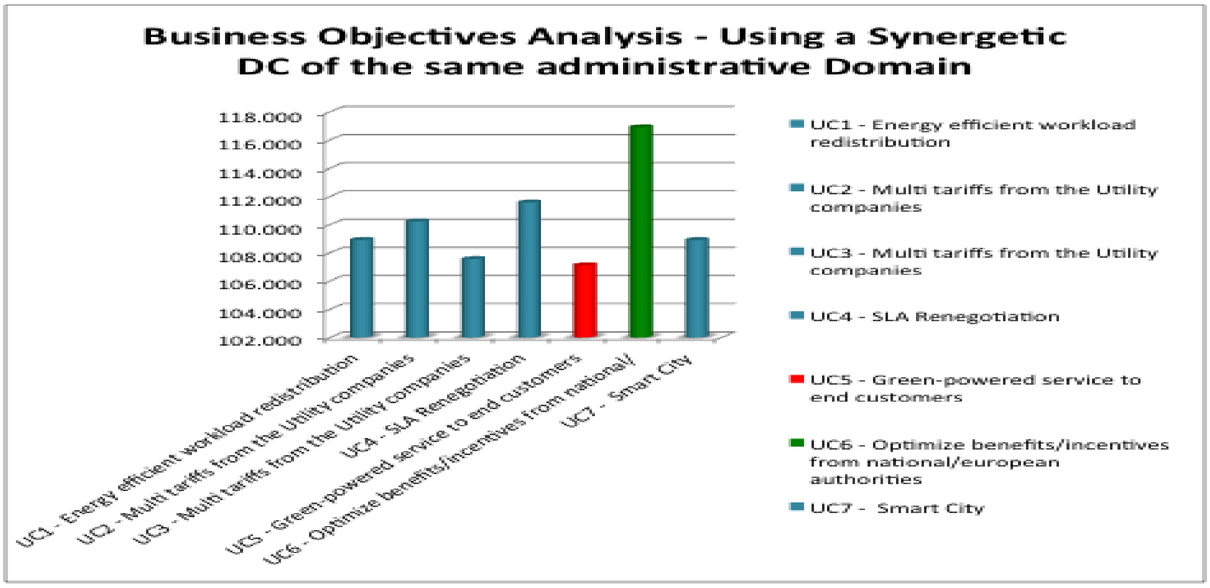

Figure 6-31: Business Objectives Analysis (synergetic Data Centre/the same administrative domain)

1 (of 7) use case is emerging to contribute most to the business objectives when using a synergetic data centre of the same administrative domain:

- UC6 - Optimize benefits/incentives from national/European authorities

4 use cases are following as contributors to the business objectives when using a single data centre:

- UC1 - Energy efficient workload redistribution
- UC2 - Multi tariffs from the Utility companies
- UC3 - Multi tariffs from the Utility companies
- UC4 - SLA Renegotiation with end customers
- UC7 – Smart City

1 other use case has a lower than average contribution to the business objectives when using a single data centre:

- UC5 - Green-powered service to end customers

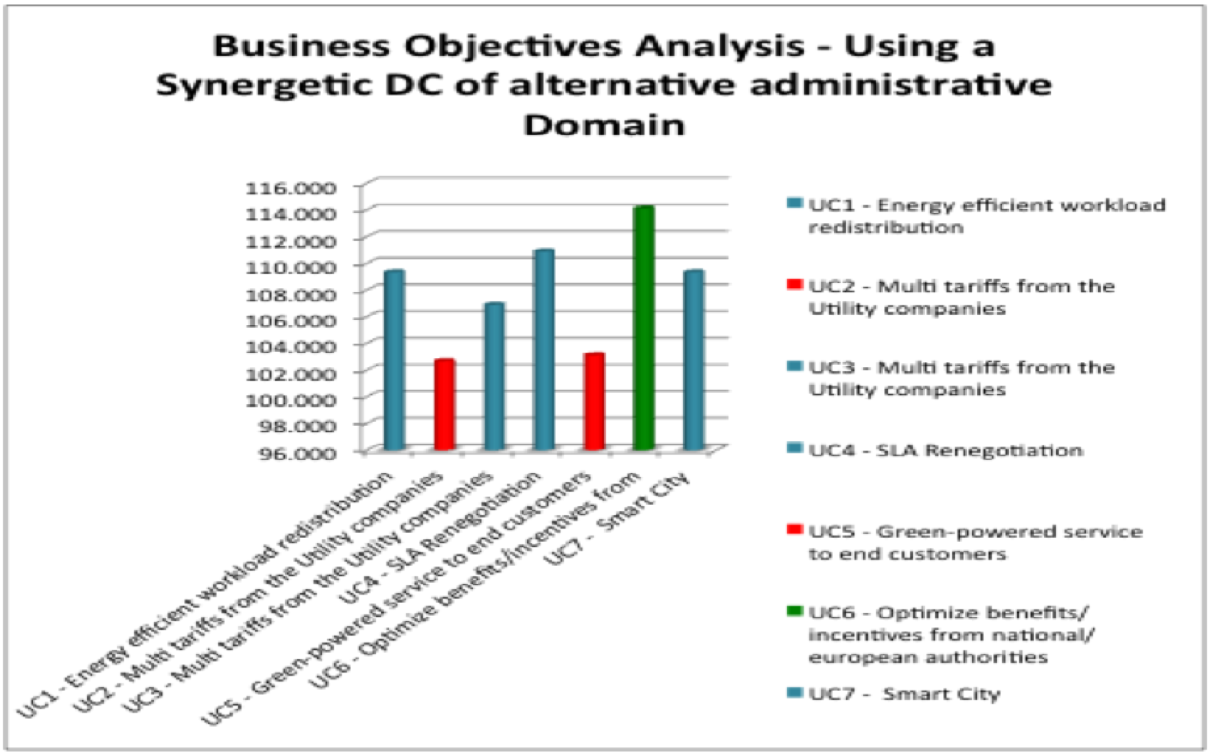

Figure 6-32: Business Objectives Analysis (synergetic Data Centre/different administrative domains)

1 (of 7) use case is emerging to contribute most to the business objectives when using a synergetic data centre of alternative administrative domain:

- UC6 - Optimize benefits/incentives from national/European authorities

4 use cases are following as contributors to the business objectives when using a single data centre:

- UC1 - Energy efficient workload redistribution
- UC3 - Multi tariffs from the Utility companies
- UC4 - SLA Renegotiation with end customers
- UC7 - Smart City

2 other use cases have a lower than average contribution to the business objectives when using a single data centre:

- UC2 - Multi tariffs from the Utility companies
- UC5 - Green-powered service to end customers

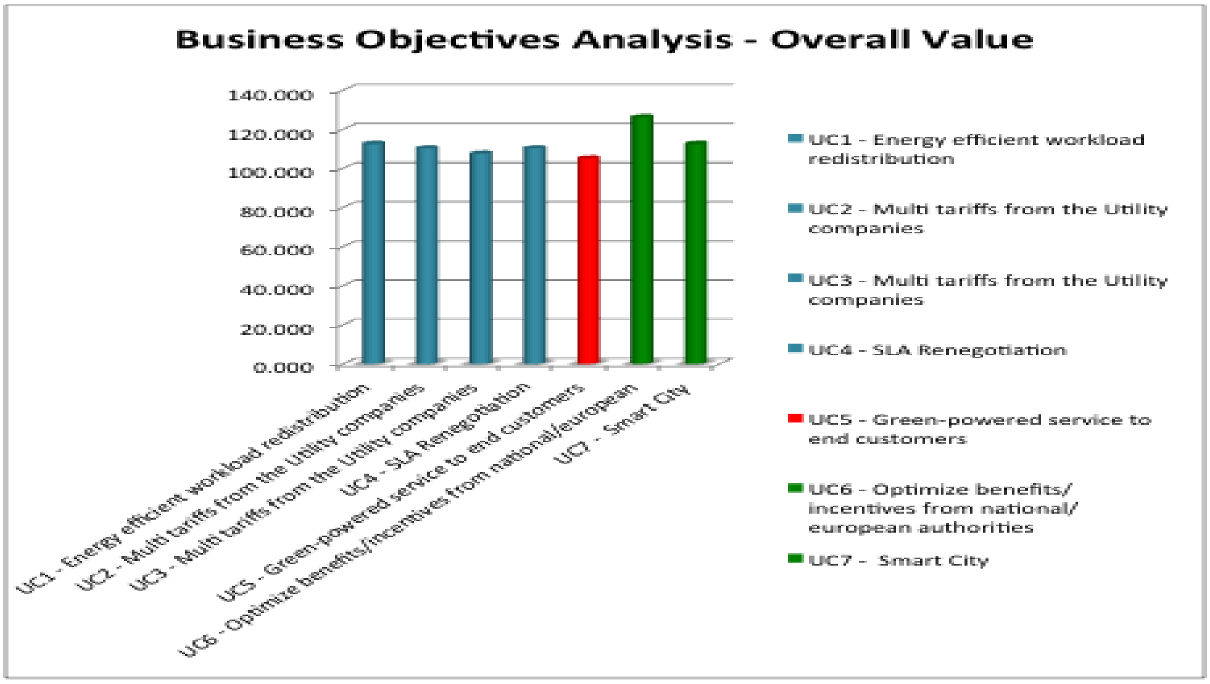

Figure 6-33: Business Objectives Analysis using QFD Overall Value

2 (of 7) use cases are emerging to contribute most to the business objectives when using QFD overall value:

- UC6 - Optimize benefits/incentives from national/European authorities
- UC7 - Smart City

4 use cases are following as contributors to the business objectives when using a single data centre:

- UC1 - Energy efficient workload redistribution
- UC2 - Multi tariffs from the Utility companies
- UC3 - Multi tariffs from the Utility companies
- UC4 - SLA Renegotiation with end customers

1 other use case has a lower than average contribution to the business objectives when using a single data centre:

- UC5 - Green-powered service to end customers

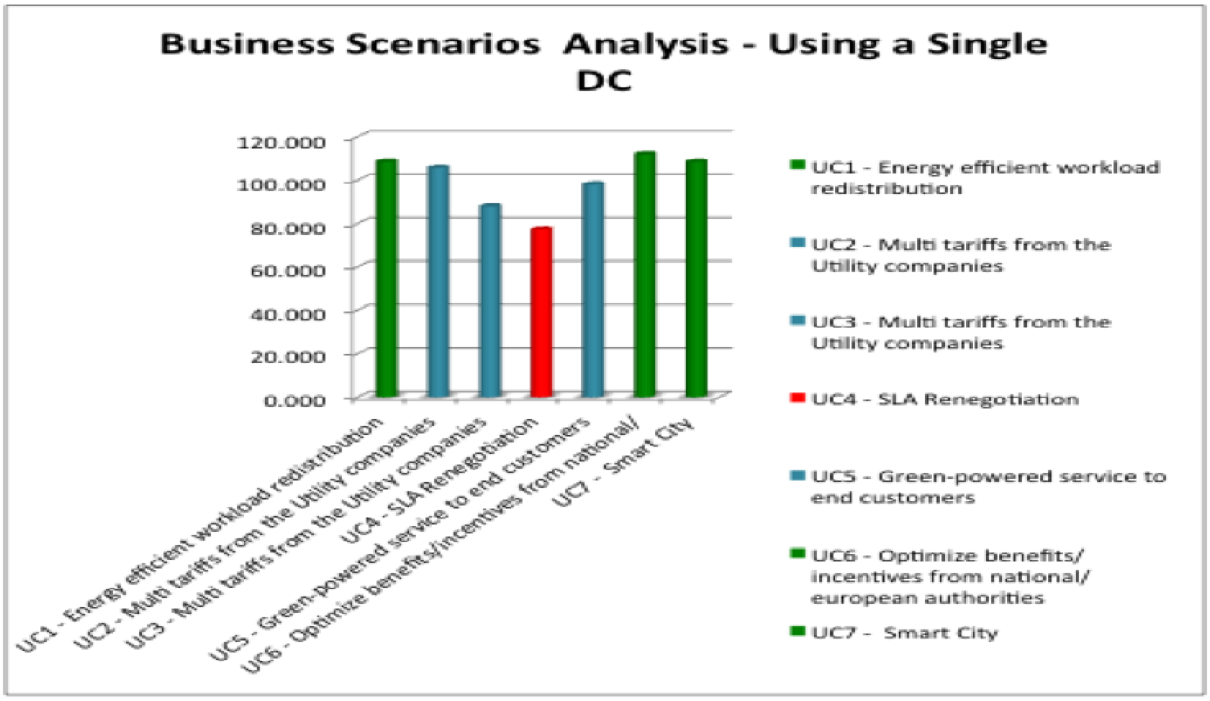

Figure 6-34: Business Scenarios Analysis (single Data Centre)

3 (of 7) use cases are emerging to contribute most to the business scenarios when using a single data centre:

- UC1 - Energy efficient workload redistribution,
- UC6 - Optimize benefits/incentives from national/European authorities
- UC7 - Smart City

4 use cases are following as contributors to the business objectives when using a single data centre:

- UC2 - Multi tariffs from the Utility companies,
- UC3 - Multi tariffs from the Utility companies,
- UC4 - SLA Renegotiation with end customers,
- UC5 - Green-powered service to end customers,

1 other use case has a lower than average contribution to the business objectives when using a single data centre:

- UC4 - SLA Renegotiation with end customers

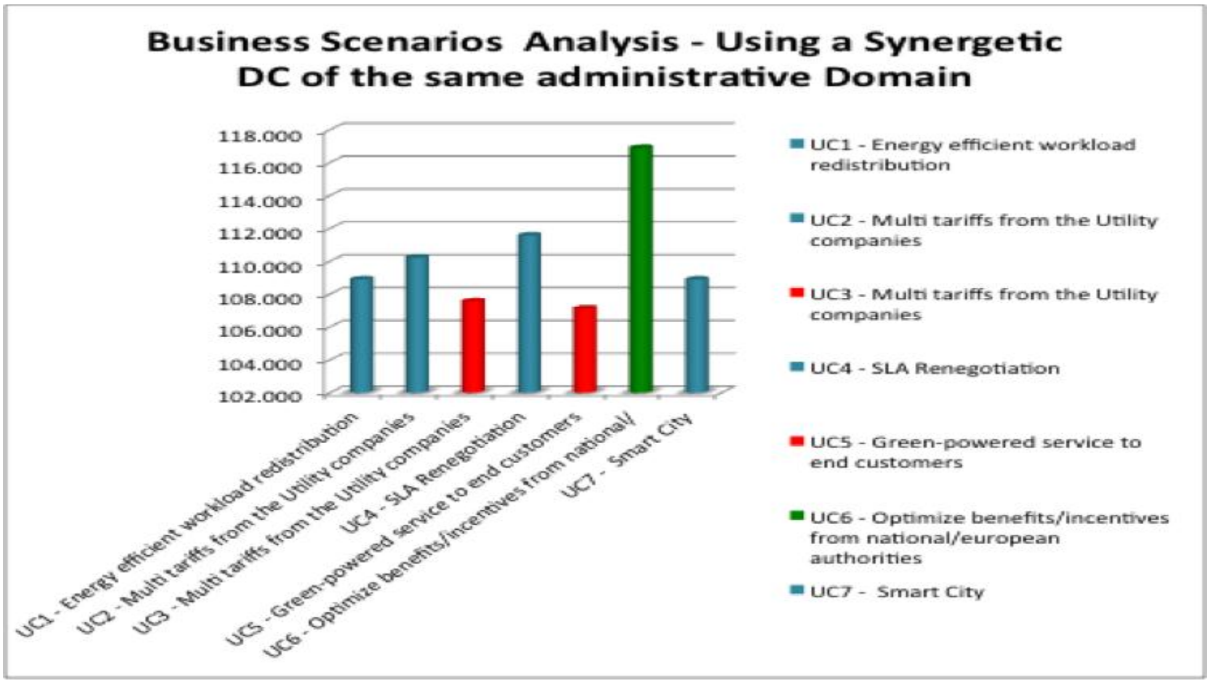

Figure 6-35: Business Scenarios Analysis (synergetic Data Centre/the same administrative domain)

1 (of 7) use case is emerging to contribute most to the business scenarios when using a synergetic data centre of the same administrative domain:

- UC6 - Optimize benefits/incentives from national/European authorities

4 use cases are following as contributors to the business objectives when using a single data centre:

- UC1 - Energy efficient workload redistribution
- UC2 - Multi tariffs from the Utility companies
- UC4 - SLA Renegotiation with end customers
- UC7 - Smart City

2 other use cases have a lower than average contribution to the business objectives when using a single data centre:

- UC3 - Multi tariffs from the Utility companies
- UC5 - Green-powered service to end customers

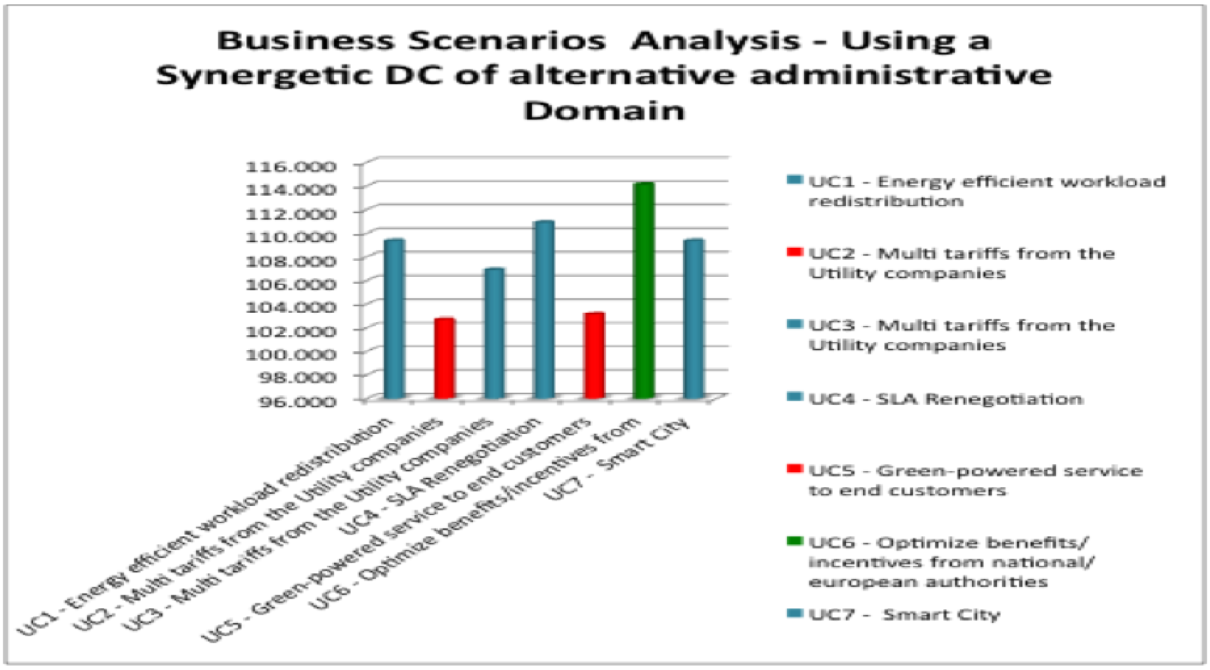

Figure 6-36: Business Scenarios Analysis (synergetic Data Centre/different administrative domains)

1 (of 7) use case is emerging to contribute most to the business objectives when using a synergetic data centre of alternative domain:

- UC6 - Optimize benefits/incentives from national/European authorities

4 use cases are following as contributors to the business objectives when using a single data centre:

- UC1 - Energy efficient workload redistribution
- UC3 - Multi tariffs from the Utility companies
- UC4 - SLA Renegotiation with end customers
- UC7 - Smart City

2 other use cases have a lower than average contribution to the business objectives when using a single data centre:

- UC2 - Multi tariffs from the Utility companies
- UC5 - Green-powered service to end customers

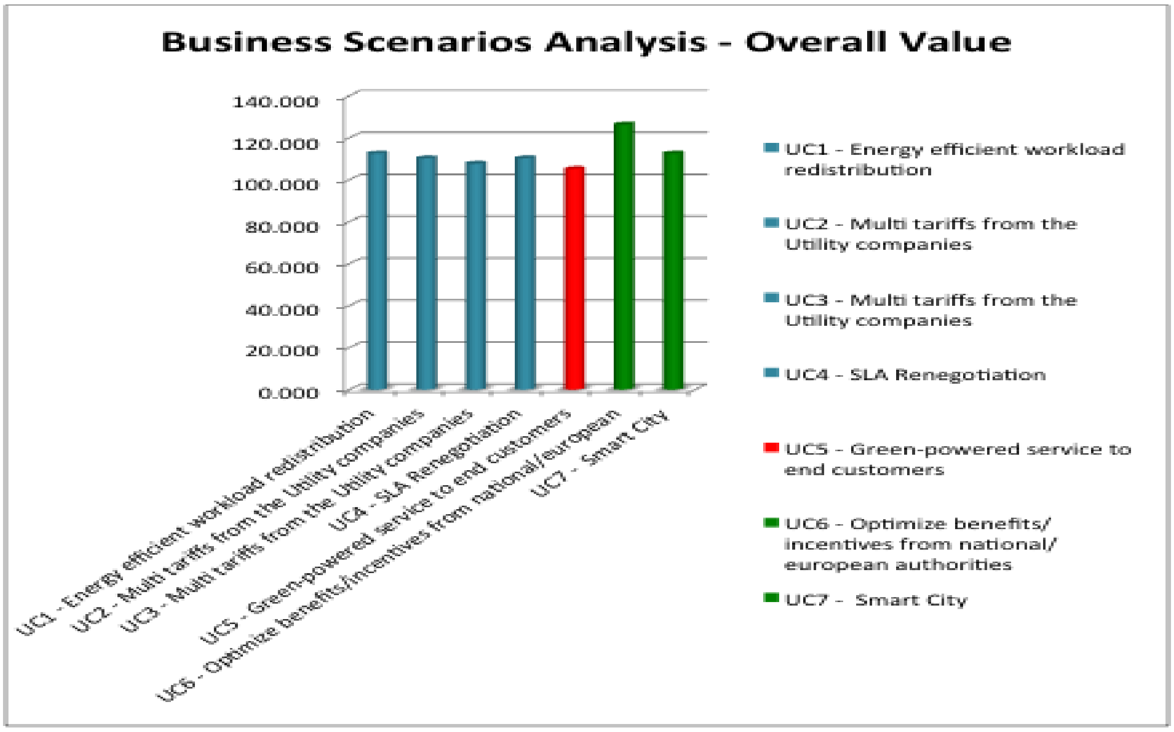

Figure 6-37: Business Scenarios Analysis using QFD overall value

2 (of 7) use cases are emerging to contribute most to the business objectives when using QFD overall value:

- UC6 - Optimize benefits/incentives from national/European authorities
- UC7 - Smart City

3 use cases are following as contributors to the business objectives when using a single data centre:

- UC1 - Energy efficient workload redistribution
- UC2 - Multi tariffs from the Utility companies
- UC3 - Multi tariffs from the Utility companies
- UC4 - SLA Renegotiation with end customers

1 other use case has a lower than average contribution to the business objectives when using a single data centre:

- UC5 - Green-powered service to end customers

7. Evaluation of the system

The following chapter will give a high-level description of the most common metrics and key parameters that will be used during next dolphin activities (mainly architectural and evaluation activities). From a correct understanding of how to set the KPI and how to measure the metrics it will be possible to effectively measure the potential of Dolfin deployment within the Data Centre infrastructure.

7.1. Energy Consumption (KPI_{EC})

The Energy Consumption, symbolised as KPI_{EC}, represents the total energy consumed by a DC, taking into account all the different types of energy sources that can be used to power the DC, both Site Infrastructure and the IT Infrastructure. The exact formula is shown below:

$$KPI_{EC} = EC_{SP} + EC_{FEN} + EC_{REN} + (EC_{TH} \times K_{TH})$$

where:

EC_{SP} : is the power consumption from the Utility Operator

EC_{FEN}: is the power consumption based on fossil local power sources

EC_{REN}: is the power consumption based on renewable local power sources

EC_{TH}: is the power consumption from externally-provided thermal energy

K_{TH}: is the conversion ratio from electricity to thermal energy Data Centre

7.2. Power Usage Effectiveness (PUE) or Task Efficiency (KPI_{TE})

One of the more established metrics is the Power Usage Effectiveness (PUE), which has been originally proposed by The Green Grid [47] and provides a measure for the overall efficiency of a Data Centre facility.

More particularly, the PUE is defined as the ratio of the total power drawn by a Data Centre facility to the power used by the IT Infrastructure (IT equipment) within that facility, as follows:

$$PUE = \frac{Total\ Facility\ Power}{IT\ Equipment\ Power}$$

The Total Facility Power is the total power consumed by the DC, summing the power consumed by the IT and the facilities equipment. The IT Equipment Power is the power drawn by the equipment used to manage, process, store or route data within the DC. PUE has received broad industry adoption as an overall facility efficiency metric. The closer to 1 the PUE is, the more efficient is considered to be the utilisation of power within the DC. Historically, a DC PUE of 2.4 to 3 (and higher) were not uncommon, indicating that as much as twice the power consumed by the IT equipment was required for the supporting facilities.

At the same time, ETSI has also defined a similar metric, called Task Efficiency (KPI_{TE}) [48] , as the ratio of the electricity consumption of all the components, whatever they are, to that of the components that manage data, for calculation storage or transport purposes. The exact formula of KPI_{TE} is shown below:

$$KPI_{TE} = \frac{EC_{DC}}{EC_{HE}}$$

where:

EC_{DC}: is the total of energy consumptions by a DC over a year.

EC_{HE}: is the total of energy consumptions by equipment processing data, for purposes of calculating, storing or transporting, over a year.

7.3. Data Centre Infrastructure Efficiency (DCiE)

An alternative metric to the PUE is the Data Centre Infrastructure Efficiency (DCiE) [47] , defined as the reciprocal of PUE as follows:

$$DCiE = \frac{IT\ Equipment\ Power}{Total\ Facility\ Power} \times 100\%$$

The DCiE is a more intuitive measure of the overall efficiency of a DC. Expressed as a percentage, this metric is similar to traditional efficiency measures and indicates the percentage of the energy drawn by the IT Infrastructure, in relation to the total power consumed by the DC.

7.4. Energy Reuse (KPI_{REUSE})

KPI_{REUSE} [48] is the ratio of reused energy for external uses to total Data Centre energy. Thermal energy can be reused in different forms, liquid or gas (air). The exact formula of KPI_{REUSE} is shown below:

$$KPI_{REUSE} = \frac{EC_{REUSE}}{EC_{DC}}$$

where:

EC_{DC}: is the total of energy consumptions by a DC over a year.

EC_{REUSE}: is the measurement of reused energy, used for water heating, heating of nearby offices/ apartments, warming of arboretums and pre-heating of diesel engines.

7.5. Data Centre Use of Renewable Energy (KPI_{REN})

KPI_{REN} [48] is the ratio of local renewable energy over the total Data Centre energy consumption. An energy source is considered renewable when it uses renewable natural energy and that the conventional energy required to value it is less than 10 % of the produced energy. Energy from renewable sources means energy that is coming from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal, ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases. The exact formula of KPI_{REN} is shown below:

$$KPI_{REN} = \frac{EC_{REN}}{EC_{DC}}$$

where:

EC_{DC}: is the total of energy consumptions by a DC over a year.

EC_{REN}: is the measurement of renewable energy.

KPI_{REN} is expected to be considered only if the amount of conventional energy required to produce it is no greater than 10 % of the produced renewable energy Data Centre.

7.6. Global Synthetic KPI (KPI_{GP})

The Global Synthetic KPI (KPI_{GP}) [48] is composed of two values DC_G and DC_P, where:

- DC_G defines the energy consumption gauge of the DC, and
- DC_P defines the performance of the DC for the relevant gauge.

Having a total number of 4 different gauges for DC_G, Table 7-1 presents the different values for DC_G, depending on the range of KPI_{EC}.

DC_G	KPI_{EC} range
S	$KPI_{EC} \leq 1$ GWh
M	1GWh ≤ KPI_{EC} ≤ 4GWh
L	4GWh ≤ KPI_{EC} ≤ 20GWh
XL	KPI_{EC} > 20GWh

Table 7-1: Possible values for DC_G

The default classes of DC_P are shown in Table 7-2 below.

DC_P Class	DC_P range	
	≥	<
A		0.70
B	0.70	1.00
C	1.00	1.30
D	1.30	1.50
E	1.50	1.70
F	1.70	1.90
G	1.90	2.10
H	2.10	2.40
I	2.40	

Table 7-2: Default classes of DC_P

Based on the definition of values found in Table 7-1 and Figure 7-2, the Global Synthetic KPIGP is presented as a combination of the two values, DCG and DCP, in the following form: Gauge, Class (e.g. M, E).

$$DC_P = KPI_{TE} \times (1 - W_{REUSE} \times KPI_{REUSE}) \times (1 - W_{REN} \times KPI_{REN})$$

where:

W_{REUSE}: is the mitigation factor for KPI_{REUSE}. The value may vary, depending on the gauge (ffs) within the range 0 to 1, with the default value being 0.5.

W_{REN}: is the mitigation factor for KPI_{REN}. The value may vary, depending on the gauge (ffs) within the range 0 to 1, with the default value being 0.5.

7.7. Data Centre Measurement, Calculation and Evaluation Methodology

The general approach to be used for the evaluation of DOLFIN can be thought of having the following steps/phases:

- Identify a set of well documented and clear KPIs or energy metrics for Data Centres.
- Define the way that these KPIs will be measured and, eventually, calculated for each one of the pilot Data Centres of DOLFIN.
- Make and initial calculation of the KPIs, without having applied any of the DOLFIN's mechanisms. In this manner we will establish a base-line for comparison.
- As the DOLFIN system becomes available, even partially, we will recalculate the KPIs. In general, recalculation of the KPIs will be done after a major change in DOLFIN system or after any significant tune-up.
- Compare the evolving values of the KPIs and establish the relationships between them and the base-line of the KPIs.

7.7.1. DC Power Metrics

Data Centres are considered as industrial facilities housing a collection of IT equipment (servers, storage and network devices) in a dedicated space. We refer to the IT portion of a Data Centre collectively as the "IT infrastructure." A Data Centre's IT infrastructure is served by the facility's power, cooling, and lighting systems, which we refer to collectively as the "site infrastructure." Data Centre energy performance is typically measured separately for IT and site infrastructure.

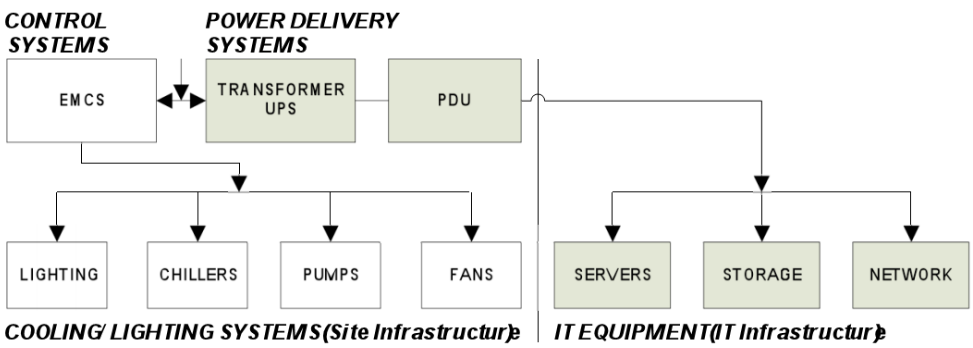

Figure 7-1: DC Power consumption and distribution architecture

The metric to assess IT infrastructure energy use and overall Data Centre utilization is a standard measurement of either billion operations per second per kW, based on load profiling from a middleware platform. Billion operations per second is also sometimes referred to as billions of processes per second (BOPS) or floating point operations per second (FLOPS). Mixed-use Data Centres typically use the metrics kW/rack and W/m^2, which vary from 2.5kW/rack to more than 20kW/rack. These estimates are based on standard four-post racks that are 42 units (roughly two meters high). The Data Centre industries (e.g., the Green Grid) are working on defining appropriate metrics to understand true IT utilization (computing horsepower) relative to net power consumption.

The most relevant metrics used to measure energy performance of Data Centres are [13] :

- Physical Server Reduction Ratio (PSRR) for IT infrastructure energy use
- Power Usage Effectiveness (PUE) and Data Centre Infrastructure Efficiency (DCiE) for site infrastructure energy use.

PSRR is the ratio of the historical installed server base to installed server base after virtualization. For example, a PSRR of 3:1 indicates a server base reduced by one-third after virtualization. Virtualization is an innovative technology that consolidates and optimizes servers, storage, and network devices in real time and thereby reduces energy use.

$$PSRR = \frac{HistoricalInstalledServerBase}{PostVirtualizatinInstalledServerBase}$$

Metrics that specifically apply to Data Centre site infrastructure include Power Usage Effectiveness (PUE) and its reciprocal, Data Centre Infrastructure Efficiency (DCiE). PUE is the ratio of total facility power to the power draw of the IT equipment:

$$PUE = \frac{TotalFacilityPower}{ITEquipmentPower}$$

For example, a PUE of 2 means that for every watt of energy consumed by IT equipment, two watts of energy are required by the entire Data Centre. Under ideal conditions, a PUE of 1 indicates that the entire Data Centre energy draw is for IT infrastructure. Data Centre Infrastructure Efficiency (DCiE) is the reciprocal of PUE, or the ratio of total IT equipment power to total facility power.

7.7.2. DC Energy use

A study of Silicon Valley Leadership Group and Accenture in 2008 found what is depicted in Figure 7-2. It shows that roughly half of standalone Data Centre energy use is for IT infrastructure. The next-biggest energy use is for cooling systems (approximately 35%). Power delivery amounts to about 11% of total energy use, and lighting about 4% or less. HVAC and lighting energy use are higher in mixed-use Data Centres because of their larger office spaces.

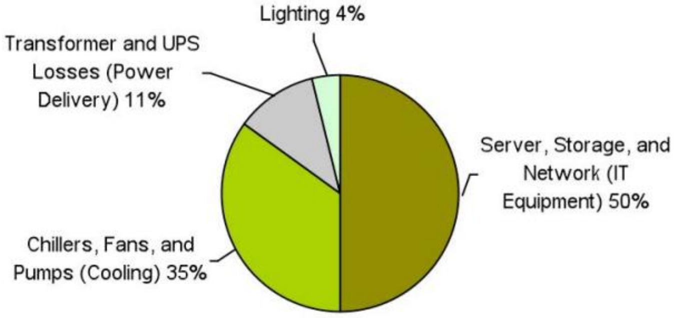

Figure 7-2: Typical DC Energy Distribution

8. Conclusions

The main purpose of this deliverable has been the DOLFIN-related drawing of business scenarios and the analysis of the use-cases. The two initial scenario foreseen in DOLFIN DoW (description of Work), namely the energy efficiency workload distribution and the demand response energy stabilization has been further analyzed and a detailed analysis of energy related topics, involving technical details and business motivations, has been produced. This analysis has followed the workflow described below:

- Description of Data Centre Operator business objectives from the perspective key themes of infrastructure optimization, energy efficiency and customer satisfaction.
- Description of the main technology enablers and the most promising techniques to allow energy efficiency within Data Centre infrastructure. The benefits of virtualization have been pointed out as well as state-of-art power management techniques (Dynamic Voltage Frequency Scaling, Dynamic Power Management, Advanced configuration and Power Interface).
- Definition of the Synergetic Approach, a framework in which Data Centres (belonging or not to the same administrative domain), team together to enable seamless and autonomic movement of Virtual Machines (Virtual Machines) for energy efficiency and power management purposes.
- Analysis of most common Data Centre Business models. The main actors interacting in DOLFIN framework has been defined, the business interaction among them has been detailed and the actual business models of Data Centre Operator have been detailed and specified in all its components with the final aim to understand which motivations and which potential impact have the energy efficiency topic on the actual business models.

The analysis conducted so far have produced a valid background to understand the topic of energy efficiency in the framework of Data Centre infrastructure and its relevance to the actual business models. Finally the following business scenarios has been created:

Absolute energy reduction: this class comprises the entire BS related to the reduction of the energy consumed by the Data Centres (equal services provided).

Power consumption manipulation to achieve the energy stabilisation: in this case, the goal is not necessarily to reduce the absolute consumption of energy, but to distribute it better geographically and temporally, in order to achieve efficiency at a higher level, that of the entire energy system.

Improve the quality of the energy mix towards environmental “friendliness”: this class includes all the BS that focus on choosing a given “energy mix” to power different services.

Starting from the business scenarios, proper use-cases have been derived, describing real world interaction among DOLFIN selected partners across the different scenarios. The use-cases have been detailed on the basis of a certain number of relevant aspect like Business Objectives, Key Actors, Revenue Stream, Customer Segment, as well as information regarding Pre/Post-conditions, Normal and Alternative flow.

A detailed description of relevant energy efficiency metrics and KPI (Key parameters indicators) have been produced, with the main purpose to provide a background information on how to monitor and measure the achievement of DOLFIN deployment within Data Centre infrastructure.

Finally, the results of the Quality Function Deployment (QFD) analysis are presented in Chapter 6 in terms of ranked business objectives / scenario objectives emerging as important/less important for each use case as well as in terms of ranked technology enablers which are emerging to contribute most/least to the use case business objectives/ scenario objectives. These results will be used as input to the requirements elicited from each use case as well as the identifying priority requirements. In addition a summary of the prioritized use cases obtained with QFD analysis is presented in Chapter 6.3.

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