Improving Energy Efficiency in Data Centers and federated Cloud Environments

Comparison of CoolEmAll and Eco2Clouds approaches and metrics

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Abstract — Significant data centers energy footprints and the increase in energy prices have stimulated investigations into possible metrics and methods to define, quantify and improve the energy efficiency of data centers and federated cloud environments, from various points of views, covering also design and operation phases. In this paper we present the two complementary energy-efficiency optimization approaches covered in scope of EU projects CoolEmAll - with focus on building energy efficient data centers, and Eco2Clouds - with focus on energy-efficient cloud-application deployment in federated cloud-environments, and describe metrics applied in these projects to assess and optimize energy-efficiency. Both approaches make use of metrics to assess energy-efficiency of data center- and cloud resources, and energy-costs of application/workload execution for various data center granularity levels and -sites.

Keywords — energy efficiency, metrics, cloud federations, energy aware data centers

I. Introduction

Significant data centers energy footprints and the increase in energy prices have stimulated investigations into methods and metrics to define, quantify and optimize the energy efficiency of data centers and federated cloud environments, from various points of views, covering also design and operation phases. In this paper we present the two complementary energy-efficiency optimization approaches covered in scope of EU projects CoolEmAll [2] - with focus on building energy efficient data centers, and Eco2Clouds [1] - with focus on energy-efficient cloud-application deployment in federated cloud-environments, and describe metrics applied in both projects to assess and optimize energy-efficiency.

In many data centers the actual IT equipment uses only half of the total energy while most of the remaining part is required for cooling and air movement [4], [5], resulting in poor cooling efficiency and energy efficiency, leading to significant CO2 emissions. For this reason issues related to cooling, heat transfer, and IT infrastructure arrangement are gaining more attention and are carefully studied during planning and operation of data centers. An important aspect when considering the energy efficiency of modular data centers is the cooling technique. The use of approaches such as “free air cooling” where external air is used to cool systems rather than electrical chillers can help to improve efficiency and achieve PUE ratings close to the ideal of 1.0. The cooling and heat transfer processes are not the only important aspects influencing the energy efficiency of data centers. Actual power usage and effectiveness of energy saving methods heavily depends on the types of IT, applications and workload properties. In order to address this, the CoolEmAll project investigates in a holistic approach how cooling, heat transfer, IT infrastructure, applications and workloads influence overall cooling and energy efficiency of modular data centers. The objective of the CoolEmAll project is to enable designers and operators of a data centre to reduce its energy impact by analyzing and combining the optimization of IT, cooling and workload management strategies. To this end, the project will provide models of datacenter building blocks and integrated tool that apply these models to simulate visualize and analyze energy efficiency of data centers on various granularity levels, while taking all above mentioned aspects into account.

The need for novel deployment strategies becomes more evident when an application spans multiple clouds. Cloud providers operate under different regulatory frameworks and cost structures in relation to environmental policies and energy value-chains. In addition, optimizing the key assets like
deployed virtual machines, applications and databases is constrained by a set of requirements such as quality, privacy and cross-platform service-level agreements. The Eco2Clouds project investigates methods and strategies that can ensure energy-efficient application deployment and execution on the cloud infrastructures in federated cloud environments, reducing the energy consumption and emissions by evaluating CO2- and energy-costs for the whole execution on each cloud-site in advance, and managing eco-efficient deployment of cloud applications based on monitoring of cloud environments and applications. The monitoring of cloud environments involves solutions applicable to physically distributed systems as well as compliant with virtualization approaches to gather relevant data regarding the energy consumption of VMs with varying work load hosted on single or distributed nodes.

Both projects - CoolEmAll and Eco2Clouds – make use of energy-efficiency metrics to describe application profiles, to assess efficiency of data center- and cloud resources, and to assess energy-costs of application and workload execution for various data center granularity levels and -sites. In this paper we compare approaches and metrics used in both projects.

The paper is divided into the following sections: Section II describes approach and metrics applied within the CoolEmAll project, in Section III we describe Eco-aware Cloud Monitoring approach and metrics used within the Eco2Clouds project, Section IV provides comparison and Analysis of approaches metrics used in both projects, finally Section V summarizes paper and presents conclusions.

II. CoolEmAll – Optimizing Energy Efficiency in Data Centers

As stated, CoolEmAll project investigates in a holistic approach how cooling, heat transfer, IT infrastructure, and application-workloads influence overall cooling and energy efficiency of data centers. In this section we describe CoolEmAll approach and its metrics used to assess energy efficiency in data centers.

A. The CoolEmAll Approach

The main goal of CoolEmAll is to develop advanced simulation, visualization and decision support toolkit (SVD Toolkit) along with blueprints of computing building blocks for data centers, enabling data center designers and operators to plan, analyze and run energy and resource-efficient facilities, minimizing the energy consumption and consequently the CO2 emissions of data centers. In order to achieve this goal CoolEmAll delivers two main outcomes:

- Design of diverse types of data centre efficiency building blocks (DEBBs) reflecting configuration of IT equipment and data centre facilities on different granularity levels (node-, node-group-, rack- and data center/container level).
- Development of the SVD Toolkit enabling the analysis and optimization of IT infrastructures built of these building blocks by means of coupled workload- and thermal-airflow (CFD) simulation.

Both building blocks and the toolkit take into account four aspects that have a major impact on the actual energy consumption: characteristics of building blocks under variable loads, cooling models, properties of applications and workloads, and resource management and workload policies. To enable the optimized design of data centers, built of optimized building blocks, these data centre efficiency building blocks (DEBBs) are precisely described by a set of metrics expressing relations between the energy efficiency and essential factors listed above. In addition to common static approaches, the CoolEmAll approach also enables studies and assessment of dynamic states of data centers based on changing workloads, management policies, cooling methods, and ambient temperature. This facilitates optimization of data centre energy efficiency also for low and variable loads rather than just for peak loads as it is usually done today. The main concept of the project is presented in Figure II-1.

In March 2013, CoolEmAll developed the 1st prototype of the Simulation, Visualization and Decision support toolkit (SVD Toolkit), enabling the assessment and user-driven optimization of the energy- and cooling efficiency in data centers by means of coupled workload- and thermal-airflow (CFD) simulation. CFD simulation calculates a heat-map indicating heat-flow distribution for various environmental conditions and cooling techniques within a server, rack or a room, enabling assessment of efficiency of a cooling system of the rack or computing room. Workload simulation enables estimation of energy or heat generation information necessary for the CFD simulations as well as estimation of performance and resource utilization. Thereby, the energy or heat generated by an application or workload, simulated in scope of the workload simulator, is calculated by evaluating the application-behavior (that specifies resource usage at different phases) and power-profile of resources (specifying power-usage at various utilization level of particular resources such as CPU, memory, network, etc.). Usage of workload simulation allows also evaluation of different resource management and workload consolidation strategies. DEBBs and SVD Toolkit are verified in scope of experiments, using various applications (HPC and Cloud), variable workloads, and various environmental conditions simulated with SVD Toolkit and executed in real and cloud based environment using Resource Efficient Computing & Storage (RECS).

Figure II-1: The CoolEmAll Approach
DEBBs are designed to model data-center building blocks on different granularity levels, from a single node up to a complete data center. In this way they can support users in modeling and simulating a data center. Within CoolEmAll, the following DEBB levels are covered:

1) **Node Unit** reflects a single computing node, e.g. a single blade CPU module.

2) **Node Group** reflects an assembled unit of building blocks of level 1, typically a server consisting of several nodes.

3) **ComputeBox1** reflects a typical rack within a data center, consisting of the building blocks of level 2 (Node Groups), power supply units and integrated cooling devices.

4) **ComputeBox2** reflects a container filled with racks or even complete compute rooms of a data centre, assembled of units of level 3 (ComputeBox1) and other facility components, such as cooling devices (chillers, heat-exchangers, HVAC, CRAC, CRAH, etc.), PDU, UPS, etc.

Thereby, a simulation of a DEBB on level n (i.e. the ComputeBox2 level), requires DEBBs of level n-1 (i.e. ComputeBox1). As stated, the focus of CoolEmAll is to simulate energy and thermal behavior of DEBBs in order to assess their efficiency and optimize design. Accordingly, metrics on each DEBB-level are classified as follows [7]:

- **Resource Usage metrics**: These metrics characterize the IT resource usage of applications and their environment. The energy consumption of an application (service) is characterized as a function of resource utilizations by a given application service, whereas resources refer to CPU, Memory, I/O, Storage, Network. Their utilization can be measured on various levels of granularity.

- **Energy metrics**: It includes metrics addressed to the energy impact of data centre considering all its components and subsystems, whereas are distinguished:
  - **Power-based metrics**: Metrics defined under power terms. The information provided is useful for designers because it drives to peak power measurements.
  - **Energy-based metrics**: Metrics defined under energy terms where the time of the measurement must be chosen.
  - **Heat-aware metrics**: The heat-aware metrics take into account temperature to characterize the energy behavior of the data centre building blocks.

- **Green metrics**: These metrics describe the impact of the operation of a data centre in the natural environment.

- **Financial metrics**: These metrics describe the financial impact of the operation of a data centre in a business organization.

The following tables (Table II-2 Table II-3 Table II-4) summarize metrics investigated within the CoolEmAll project capable to assess (test bed and simulation based) experiments, and building blocks (DEBBs) on different granularity levels. For detailed definition of metrics, please refer to [7]. Metrics marked by “P” are primary metrics that are used and evaluated in scope of the project; by “S” marked metrics are currently under consideration. In addition to these metrics, CoolEmAll defines also 13 application level metrics called Application Performance Factors (APF), which measure min/max/average power- and energy-usage, as well as maximum/mean latency or SLA violations during the execution of applications or within certain time-period.

It should be highlighted, that the CoolEmAll approach is focusing merely on heat-aware metrics of data centre in order to optimize the cooling-efficiency directly from the former site where energy consumption is originated, the node, node-group, or rack [6]. In this context, the CoolEmAll suggested new metrics, comprising the Imbalance of Temperature on node, node-group and rack level, and Rack Cooling Index adapted to node-group level, which are currently under evaluation.

<table>
<thead>
<tr>
<th>Node</th>
<th>Resource-Usage</th>
<th>Power-Based</th>
<th>Energy-based</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CPU Usage</td>
<td>Node Power Usage</td>
<td>Node Cooling Index</td>
</tr>
<tr>
<td></td>
<td>Server Usage</td>
<td>MHz/Watt</td>
<td>Heat Index</td>
</tr>
<tr>
<td></td>
<td>Network Usage</td>
<td>Bandwidth/Watt</td>
<td>Max &amp; mean heat dissipation</td>
</tr>
<tr>
<td></td>
<td>Memory Usage</td>
<td>Capacity/Watt</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Storage Usage</td>
<td>IOPs/Watt</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PDU Device Usage</td>
<td>Power vs. Utilization</td>
<td></td>
</tr>
</tbody>
</table>

**II-1: Node level metrics**
It should be noted, that many metrics used within CoolEmAll are originated from the Games Project [13]. The relationship between the Green Performance Indicators (GPI) layers identified within the GAMES project described in [12] and CoolEmAll layers is clarified in Table II-5.
As can be seen, two Zabbix monitoring aggregators are used in order to retrieve the whole amount of monitoring information. The infrastructure aggregator captures values for the physical infrastructure including the energy metrics and the infrastructure domain information whereas the Zabbix virtual machine aggregator captures information about the transient virtual machines and the services running on them. Using a template and metric passing interface, the virtual machine aggregator is able to retrieve the underlying monitoring information and through that, combining these metrics to provide powerful combined ones. Using that monitoring information and through that, combining these metrics to provide powerful combined ones. Using that mechanism allows the scheduler to gather information about the four different layers at once – including combinations between all of them.

In order to clarify the identified, measured metrics, the most important ones will be presented exemplarily. On infrastructure layer, two important metrics are defined by the CPU utilization and current energy consumption, especially for multi core systems. Power consumption of the physical hosts decreases in percent if more cores are used because of the IDLE state of the CPUs. With that fact, loading a single host instead of two decreases total energy consumption.

For the virtual layer, those two metrics count as well. The energy consumption of a VM can be estimated using the formula presented by Katsaros, et. al. [11]. This formula defines the energy effectiveness for each node \( \text{Ef}_{\text{Node}_i} \). The formula expects the CPU utilization in a range between 0 and 100 independently from the number of running processes and hence \( U_{VM,j} \) is identified as the total amount of CPU time to be consumed by a server, not a single core. It presents the CPU consumption of a given VM \( j \) on node \( i \). PUE is the general power usage effectiveness, \( R_j \) identifies the real power consumption of the given node, \( P_{\text{Node}_i} \) indicates the computing performance (operations per seconds) of the node \( i \).

\[
\text{Ef}_{\text{Node}_i} = \left( \frac{\Sigma_j U_{VM,j}}{100} \right) \times P_{\text{Node}_i} / R_j \times \text{PUE}
\]

The energy consumption of a VM depends massively on the underlying physical hardware – different kinds of CPUs have different kinds of energy consumption. Migrating a VM to another host may decrease power consumption heavily; the overall performance is not taken in account in that case.

The service metrics mainly consider the performance of the application. Reducing energy consumption on the one hand, the application still has to perform. An important metric is the application execution time, which represents the overall performance of a deployed application. Using this metric in combination with the power consumption provide information about the greenness of an application. Furthermore, requirements may be changed in order to deploy the application in an optimized way.

In order to measure the carbon footprint of the deployment and the application, the site layer needs to be regarded as well. Information about the energy mix can only be obtained by the provider directly. Coupling the power consumption with the energy mix provides information about the produced \( \text{CO}_2 \) for the used energy. With that metric, the carbon footprint of an application can be calculated.

For the execution, an application profile is required which consists of execution parameters based on the developers ideas. For instance, maximum performance can be taken as well as maximal eco-efficiency of an application. Using those values, the scheduler calculates the optimal deployment strategy in order to fulfill the requirements in the best fashion and finally deploys the virtual resources.

During the execution, the scheduler observes all the monitoring parameters to review the deployment situation and react if necessary: new virtual machines can be requested, unused released, application performance may drop or the energy consumption could increase. In special heavily frequented cloud providers with an amount of started and stopped resources face a lot of disturbing factors, so changing parameters are very common. If the facts change, the suboptimal deployment needs to be modified in order to fulfill the requirements of the application. Migrating virtual machines in-site, so from one host to another or site-wide, changing the provider in general are options that can be regarded. Furthermore, vertical and horizontal elasticity can be regarded as well to improve the overall performance and energy consumption. For possible migrations, the spent overhead is also taken into account.

After the execution, a summary is generated containing all the necessary information like total runtime, resource usage, power consumption and the carbon footprint of the deployment. Analyzing these facts offers the possibility to overwork the application profile to improve the whole application. Furthermore, the scheduler takes into account previous executions including the monitoring information to optimize the deployments the best way. For that purpose, old
monitoring data needs to be processed to keep the databases small and an efficient performance of the scheduler. Data mining algorithms are used to reduce the dataset and provide important information of previous executions.

The presented approach shows that ECO²Clouds is represented as service located above the local cloud middleware in order to provide an energy efficient deployment strategy for cloud applications.

B. Monitoring Metrics

The defined ECO²Clouds metrics are divided into three categories, the physical layer, the virtual layer and the application layer. All of the three layers are making use of energy related data. The energy related data are measured by using so called Power Distribution Units (PDU) in order to combine the energy data with the data of the three mentioned layers and calculate the energy consumption for the infrastructure, the virtual machines (VMs) and the applications hosted in the VMs.

The following tables (Table III-1, Table III-2 and Table III-3) present the metrics used for calculating relevant data regarding the energy consumption of the infrastructure and the deployed VMs. The energy consumption of the application layer depends on the certain configurations of each application. Metrics on application level are described in [9].

<table>
<thead>
<tr>
<th>Table III-1: Infrastructure Metrics for the Host</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metric</td>
</tr>
<tr>
<td>CPU utilization</td>
</tr>
<tr>
<td>Availability</td>
</tr>
<tr>
<td>Energy consumption</td>
</tr>
<tr>
<td>IOPS/Energy consumed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table III-2: Infrastructure Metrics for the Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metric</td>
</tr>
<tr>
<td>Site utilization</td>
</tr>
<tr>
<td>Storage utilization</td>
</tr>
<tr>
<td>Availability</td>
</tr>
<tr>
<td>Green Efficiency Coefficient (GEC)</td>
</tr>
<tr>
<td>PUE</td>
</tr>
<tr>
<td>Site Infrastructure Efficiency</td>
</tr>
<tr>
<td>Site Energy Productivity</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table III-3: Virtual Machine Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metric</td>
</tr>
<tr>
<td>CPU usage</td>
</tr>
<tr>
<td>Storage Usage</td>
</tr>
<tr>
<td>I/O Usage</td>
</tr>
<tr>
<td>Memory Usage</td>
</tr>
<tr>
<td>Energy consumption</td>
</tr>
<tr>
<td>IOPS/Energy consumed</td>
</tr>
</tbody>
</table>

IV. Comparison and Analysis

In this section we compare and analyze approaches as well as metrics used within the both projects. The comparison of approaches will involve following dimensions:

- **Approach type**: simulation/model based vs. real/situation based
- **Data Center lifecycle phases** [10]: planning, design, construction, commission, turnover & transition, operation
- **Granularity level**: node, node-group (server), rack, data center, federation of data centers
- **Application type**: HPC, Cloud
- **Level of details**: how many levels are covered in scope of the approach (high, medium, low)
- **Scope**: how broaden is the scope covered within the approach (high, medium, low)

As many metrics used within the both projects – CoolEmAll and Eco2Clouds were initially introduced in GAMES project and have the same meaning, their comparison will be metric by metric.

A. Comparison of Approaches

In this section we summarize comparison of the two approaches used within the CoolEmAll and Eco2Clouds projects, presented in Table IV-1.

The CoolEmAll approach is characterized by simulation/model and situation based approach and addresses primary: (i) the planning phase, enabling evaluating various environmental conditions and their impact on energy-
efficiency of data-center allowing select the right geographical location, and (ii) design phase, enabling evaluation of different data center configurations in advance, on various granularity levels - from a node up to a complete data-center. Secondary, the CoolEmAll approach addresses also the (iii) operational phase, allowing evaluating (a) energy-impact of various configurations induced by adding or removing new/old equipment, (b) analyze and apply different resource-management and workload scheduling strategies to reduce the energy-consumption and optimize efficiency. CoolEmAll supports simulation and execution of both application types: HPC and Cloud related application, involving virtual machines. Models used within the CoolEmAll approach provide very high level of details and broad scope, comprising all components of particular (DEBB) level, and, allowing analysis of dynamic loads.

The Eco2Cloud approach is characterized by situation based (i.e. evaluation of monitored PUE) approach and addresses only the operational phase, according to predefined scheduling objectives and preferences stated in application-profile. The prediction of the efficiency of application-deployment is based on productivity calculation, determined by the computing performance and power-consumption of the nodes / servers, CPU-consumption of VM on particular nodes/servers, and monitored and steadily updated PUE values of the cloud sites. The Eco2Cloud approach affects following granularity levels: (i) node, (ii) server level (node-group), (iii) site or data-center level and (iv) federation of data-centers. The focus of Eco2Clouds is virtual environment (VM), hence cloud applications and services are primary of interest for Eco2Clouds.

The additional layers (Rack and Node-Group) introduced in CoolEmAll are used to model and assess efficiency on particular level. The following tables (Table IV-3, Table IV-4, Table IV-5, Table IV-7) summarize and compares the metrics used within the both projects ("s" marked metrics are currently under consideration and will not be compared in this paper). In next section we provide analysis of compared metrics.

<table>
<thead>
<tr>
<th>Comparison kind</th>
<th>CoolEmAll</th>
<th>Eco2Clouds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach type</td>
<td>model/simulation based (real/situation based to learn and validate models)</td>
<td>real/situation based</td>
</tr>
<tr>
<td>Lifecycle phases</td>
<td>primary: planning, design secondary: operations</td>
<td>operations</td>
</tr>
<tr>
<td>Granularity levels</td>
<td>node, server, rack, data-center</td>
<td>node, server, data-center, federation</td>
</tr>
<tr>
<td>application types</td>
<td>HPC, Cloud</td>
<td>Cloud</td>
</tr>
<tr>
<td>Level of details</td>
<td>very high</td>
<td>low/medium</td>
</tr>
<tr>
<td>Scope</td>
<td>broad</td>
<td>limited</td>
</tr>
</tbody>
</table>

Table IV-1: Comparison of approaches

B. Comparison of Metrics

As noted, both projects – CoolEmAll and Eco2Clouds - use many metrics that have been initially introduced in scope of the GAMES project. This simplifies their definition and comparison. The correspondence between the layers used in scope of GAMES and CoolEmAll projects were presented in Table II-5. The layers (and many metrics) used in scope of Eco2Clouds project are equal to those introduced by GAMES project, and were extended by virtualization layer. Hence, correspondence between the layers in CoolEmAll and Eco2Clouds projects can be summarized according to Table IV-2:

Table IV-2: Comparison of layers

<table>
<thead>
<tr>
<th>GAMES GPI</th>
<th>Eco2Clouds</th>
<th>CoolEmAll</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organization</td>
<td>Organization</td>
<td>Out of the focus of CoolEmAll</td>
</tr>
<tr>
<td>Facility</td>
<td>Cloud Site</td>
<td>Data Centre</td>
</tr>
<tr>
<td>Compute Node</td>
<td>Compute Node</td>
<td>Node-Group</td>
</tr>
<tr>
<td></td>
<td>Virtualisation</td>
<td>Addressed in scope of (cloud) applications</td>
</tr>
<tr>
<td>Application</td>
<td>Application, Services</td>
<td>(HPC, Cloud)</td>
</tr>
</tbody>
</table>

Table IV-3: Node level comparison

Table IV-4: Node-Group level comparison
Table IV-5: Rack level comparison

<table>
<thead>
<tr>
<th>Metric</th>
<th>Data Center / Site</th>
<th>Rack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource-Usage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power-Based</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPS Usage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat exchanger Usage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rack Productivity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat-aware</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rack Cooling Index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rack Humidity Index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imbalance of temperature of Node-Groups</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imbalance of heat generation of Node-Groups</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table IV-6: Data Center/Site level metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Data Center / Site</th>
<th>Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource-Usage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power-Based</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPS Usage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Centre Utilisation (DCU), equivalent to Site utilization</td>
<td>s</td>
<td>X</td>
</tr>
<tr>
<td>Power Usage Effectiveness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUE Scalability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat-aware</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imbalance of temperature of Racks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imbalance of heat generation of Racks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air management indicators</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green metrics</td>
<td></td>
<td></td>
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<tr>
<td>Primary Energy Balance</td>
<td></td>
<td></td>
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<tr>
<td>Green Energy Coefficient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Reuse Effectiveness (ERE)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Usage Effectiveness (CUE) [gCO2e/kWh]</td>
<td>s</td>
<td>X</td>
</tr>
<tr>
<td>Water Usage Effectiveness (WUE)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KPIs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Centre Performance Per Energy (DPPE)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon emissions balance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Financial</td>
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<td></td>
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<tr>
<td>CAPEX</td>
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<td>OPEX</td>
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<tr>
<td>TCO</td>
<td></td>
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<tr>
<td>Playback Return</td>
<td></td>
<td></td>
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<tr>
<td>ROI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon credits</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table IV-7: Virtualization level comparison

<table>
<thead>
<tr>
<th>Metric</th>
<th>CPU Usage</th>
<th>Network Usage</th>
<th>Memory Usage</th>
<th>Storage Usage</th>
<th>IO Device Usage (IOPS)</th>
<th>VM Power Usage</th>
<th>VM-PUE</th>
<th>Energy Consumption of VM</th>
<th>VM-GE (VM Green Efficiency)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual Resource-Usage</td>
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C. Analysis of metrics

As noted, CoolEmAll and Eco2Clouds make use of energy-efficiency metrics (i) to describe application and hardware profiles, (ii) to assess efficiency of data center- and cloud resources/sites, and (iii) to evaluate predictably energy-costs and carbon usage of application and workload execution for various data center granularity levels and –sites. The analysis of the metrics used in both projects will be done according to these considerations.

Application profiles (i) in both approaches are described using resource-usage metrics. Thus, resource-usage metrics on node and node-group level in both projects are mostly identical. However, CoolEmAll has more detailed application profile (focusing on resource causing high power-usage), specifying in addition to CPU-Usage also Memory (and Network Usage). In contrast, Eco2Clouds specifies usage of storage and IO Devices. Virtual resource usage metrics on virtualization level are assessed similarly, however Eco2Clouds measures here in addition also memory-usage.

To assess energy-efficiency (ii) of data center- and cloud resources, power and energy consumed by resources needs to be monitored. On node and node-group level, power and energy-usage (productivity as a relationship between useful-work/capacity and energy used) metrics in both projects are almost the same (SWaP is exception). On Rack and Data Center/Site level, there are some differences (only PUE are used equally in both projects). As the focus of CoolEmAll is to enable study of dynamic loads, metrics such as FVER and PUE Scalability are considered here more detailed.

To assess cooling-efficiency, CoolEmAll approach uses heat-aware metrics (described on all granularity levels). This aspect is not addressed in Eco2Clouds.

Green metrics are used to assess ecological impact (iii) of energy-consumption of application-execution (carbon usage of application). Most of the Green metrics (GEC, CUE) are applied within the Eco2Clouds project, as the focus of this project is to evaluate ecological impact of application executed on various (cloud) sites. The aspect addressed in CoolEmAll affects mainly cooling-efficiency, metered by WUE metric.

The Availability or resources is used only within the Eco2Clouds project. However, this metric might be also of interest for the CoolEmAll project, as operating data-centers are higher temperature affects availability of resources.

v. Conclusions

In this paper we compared and analyzed approaches and metrics used within the projects CoolEmAll – with focus on building and assessing energy efficient data centers and (ii) Eco2Clouds – with focus on ecological-aware application deployment. It turned out, that some metrics used within the both project are very similar, as they originate from the Games project. The difference between the other metrics is a result of different project-focuses, life-cycle-phases, approaches covered in scope of the projects, depth, spectrum and application-types.
The two approaches can be combined in several ways, i.e., applied according their life-cycle phases: (1) use CoolEmAll approach to design energy-efficient data-centers; (2) use Eco2Clouds approach to deploy application ecologically aware, selecting the most efficient and ecological data-centers or cloud-site. The overlap between the both projects will be discussed at the EuroEcoDC 2013 workshop to facilitate exchange of knowledge and experience between the two projects in the domain of Green-IT.

Acknowledgment

This work has been supported by the CoolEmAll (http://coolemall.eu) and ECO2Clouds (http://eco2clouds.eu) projects and has been partly funded by the European Commission’s IST activity of the 7th Framework Programme under contract numbers 288701 and 318048. This paper expresses the opinions of the authors and not necessarily those of the European Commission. The European Commission is not liable for any use that may be made of the information contained in this paper.

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