DC4Cities
An environmentally sustainable data centre for Smart Cities

Project Nº 609304

WP7 Deliverable 7.3
Final DC4Cities standardization framework and results description of the European Cluster

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EXECUTIVE SUMMARY

In project DC4Cities, WP7 focuses on the establishment of a recognized set of metrics, both to answer the need of tools to measure energy, environmental and economic parameters in a Data Centre (DC), and to assess improvements and/or achievements of the technologies developed within the project. In this deliverable we provide a summary of the complex activity that was carried out within the framework of the Cluster, a joint endeavour among a number of FP7 and Horizon 2020 projects that was promoted by the European Commission, and that was set up and coordinated by DC4Cities. The main results of this analysis were presented to the Cluster in the meeting held on 4th March 2016 in Barcelona.

Experiences in the use of metrics within DC4Cities trials are also presented, as a possible contribution from DC4Cities to future Cluster activities dissemination activities.

Chapter II describes activities and results of the Smart City Cluster Collaboration, an joint initiative of (currently) 7 EU projects, with the primary goal of identifying common Key Performance Indicators (KPIs), developing measurement & verification methodologies, comparing results across projects. In this last year of activity, the metrics and methodology frameworks - that had been defined in the previous years of activity of the Cluster – have been presented to standardization bodies with the aim of boosting the standardization of energy and environmental KPIs for Data Centres. Moreover, from 2016 the activity of the cluster is going to be also focused on sharing experiences among the projects, with the aim of retrofitting the initial development tasks and improve, if applicable, the defined KPIs and methodologies.

Chapter III presents progress on another line of activity that was pursued in DC4Cities: workload related metrics. On this topic, a review on workload-related metrics case studies – based on literature works - that used benchmarks approaches is presented. Moreover, progress made on the experimental campaign on workload-related metrics carried out by ENEA is also presented. Using different benchmarks, further experiments to assess energy consumption of applications were carried out at ENEA premises, using various set-ups designed to simulate and study the effective energetical behaviour of a DC delivering a standard service such as that of a webserver.
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I. INTRODUCTION

I.1. Purpose and organization of the document

The work presented here builds on results accomplished in the previous two years of the project and presented in Deliverables:

- D7.1, in which, after a thorough analysis, it was agreed that metrics currently recognized and employed in the industry and academia give only a very partial answer to the need for reliable energy measurement processes in Data Center (DC), all the more so when a DC powered by renewable energies is considered.

- D7.2, in which the work has been developed around two different strategies, one all internal to the project DC4Cities, and the other within the framework of the Cluster multi-project collaboration.

In detail, in the present Deliverable work was finalized and metrics results coming from other DC4Cities WPs, in particular WP2 and WP6 (trials results) were integrated. A dedicated section on the project metrics results is presented. Within DC4Cities trials the existing metrics and new KPIs (RenPercent, APC, DCA, Energy Expenses Saving, CO2 Savings, Primary Energy Savings, Federation metrics) and also their methodologies - development both at Cluster and at Project level - have been tested. Computability and usefulness were appropriately evaluated.

The following Chapter (Chapter II) describes the activities carried out in the framework of the Cluster collaboration. Essentially, these consist in the finalization of methodologies and verification plans for two separate sets of metrics, one including metrics already existing and often in use, and the other made with a selection of the new metrics that had been defined in the previous year of activity of the Cluster. This material was summarized and shared with Cluster partners as a contribution to the future activities of refining metrics and methodologies, which will be carried out by the Cluster after the end of DC4Cities.

Since DC4Cities aims at making progress in this domain also from the point of view of policies, and wants to stimulate a discussion among different stakeholders in order to foster the adoption of its results by the ICT sector, a list of interactions with international standardization bodies and dissemination activities is also presented.

Chapter III presents further progress in terms of workload related metrics; a collection of case studies on workload-related metrics – based on literature works - that used benchmarks approaches is presented. In detail, the work shows the progress made on the workload related metrics through: an overview of recently case studies on workload-related metrics using benchmarks procedure and an introduction of workload-related metrics in HPC systems.

In order to complete a scenario on workload related metrics, Chapter III presents the progress about a campaign of experiments carried out in ENEA. This activity follows up on what was previously described in D7.2: measures on energy consumption of applications were carried out at ENEA premises, using various set-ups designed to simulate and study the effective energetical behaviour of a DC delivering a standard service such as that of a webserver using different benchmarks.

Work performed in WP7 and presented here has strong connections with several other areas of activity of DC4Cities and particularly with WP2 and WP6, in which metrics and methodologies have been employed and put to test.

Typical recipients of this document include all main stakeholders in the datacentre business, whether industry-based or coming from academia and research, and all parties interested in the problem of establishing an adequate system of energy-based metrics in the IT sector. As stated before, other interested parties include the international bodies of standardisation, to which the final results of this effort are specifically aimed.
II. ACTIVITIES WITHIN THE CLUSTER

This chapter describes activities and results of the Smart City Cluster Collaboration, a joint endeavour engaged by the European Commission of (currently) 7 EU projects, with the primary goal of identifying common Key Performance Indicators (KPIs), developing measurement and verification methodologies and comparing results across projects.

In this last year, the metrics and methodology frameworks - that had been defined in the previous years of activity of the Cluster – have been presented to standardization bodies with the aim of boosting the standardization of energy and environmental KPIs for Data Centres. Moreover, from 2016 the activity of the cluster is going to be also focused on sharing experiences within each project, with the aim of retrofitting the initial development tasks and improve, if applicable, the defined KPIs and methodologies.

II.1. Overview of the Cluster activities and organization

The Smart City Cluster is composed by all the projects from FP7-SMARTCITIES-2013 Objective ICT-2013.6.2. “Data Centres in an energy-efficient and environmentally friendly Internet”: DC4Cities, RenewIT, Dolfin, GENiC, GreenDataNet, GEYSER and project EURECA from H2020. Two more projects were initial Cluster members (All4Green and CoolEmAll), but both projects have finalized during 2015. Nevertheless, their members are still linked to the Cluster through their participation in other Cluster projects (DC4Cities and RenewIT).

The main objective of the Smart City Cluster is to define common parameters and ratios (metrics, Key Performance Indicators) to characterize the energy, environmental and economic behavior of Data Centres (DCs). The goal is to allow valid cross-project comparison between Cluster members as well as to provide standardization bodies and other stakeholders with DC efficiency-related information to allow more environmentally friendly procurement/exploitation of IT services.

In this section, an overview of Cluster activities and organization is provided.

II.1.1. Cluster activities and organization

The Cluster has structured its works in 6 Tasks in order to achieve the goal; each Task has its own leaders and collaborators.

In particular, Tasks 1, 2, 3, 4 have been finished and reported to the European Commission, and their results are summarized in Deliverable 7.1 and 7.2. Furthermore, the reports on the Cluster’s Task 3 and Task 4 are publicly available

In detail, the Tasks 1, 2 and 3 have consisted in identifying existing KPIs, analyzing them in order to determine strengths and limitations, and consequently proposing new KPIs or modifications in existing ones; Task 4 has proposed common methodologies for calculating most of the KPIs defined by the Cluster in Task 3. KPIs used by less than two projects have been discarded at the beginning of Task 4 by the Cluster and therefore no application methodology will be developed at Cluster level (see D7.2 III.1.2 for more details).

Thanks to the Cluster' work, a set of new KPIs and methodologies has been defined, which jointly allow quantifying all the relevant parameters that must be measured to assess DC energy, environmental and economic behaviour in projects.

The Cluster has also liaised with standardization bodies and discussed existing methodologies to be standardised as well as disseminated new KPIs for possible future standardisation (Task 5). Furthermore, the Cluster members have been present in events and disseminated Cluster activities to related stakeholders. In order to communicate the relevant information, and widely

exploit and disseminate the work performed within the Cluster, a dissemination plan has been developed.

Experimental results from trials will be shared and discussed among the different Cluster projects (Task 6). The discussion and its conclusions will serve as input for refinement of developments from Tasks 3 and 4 (metrics and methodologies), which will result in updated version of the corresponding Cluster documents.

The following chart shows the Cluster’ activities scheduled until the end of the Cluster’s collaboration.

**Figure 1 Interaction among the Cluster’s Tasks**

<table>
<thead>
<tr>
<th>Task 1 - Identify existing metrics</th>
<th>Task 2 - Analyze existing metrics and determine their limitations and weak points</th>
<th>Task 3 - Propose new metrics based on the existing ones that improve these limitations</th>
<th>Task 4 - Propose a common methodology for all DC projects to measure the defined metrics</th>
<th>Task 5 - Provide results to CEN/CENELEC/ETSI Coordination Group</th>
<th>Task 6 - Share experimental results</th>
</tr>
</thead>
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<tr>
<td>Finished</td>
<td>In progress</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>2015</td>
<td>2016</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DC4Cities project has been in charge of coordinating cluster activities. As can be observed, it is expected that the collaboration between projects will be extended beyond the end of DC4Cities project, especially to continue disseminating cluster results, collaborating with standardization bodies and sharing experiences gathered in the project trials. In accordance with the EC and EURECA project, after the end of DC4Cities project, EURECA will be the responsible of coordinating cluster activities.

The description of the main objectives of the tasks and their results are provided in the following paragraphs.

**II.2. Task 1**

The Task 1 aims at identifying existing metrics, which need to be representative for all energy, environmental and economic parameters that need to be measured by the different cluster projects. The main objectives of this task are:

- to identify state of the art metrics for measuring the energy, environmental and economic behaviour of data centres;
- to classify the metrics according to categories, defined taking into account the parameters to be measured by the projects part of the Smart City Cluster Collaboration.
According to the table in Figure 2 this activity started in January 2014 and finished in February 2014. Task 1 was led by TUC (GEYSER).

The main activity of this task has been to list and classify more than 40 indicators, which could be found in the state of the art literature. The below classification table has been used to sort indicators:

<table>
<thead>
<tr>
<th>Indicator Name</th>
<th>Classification Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy / power consumption (loads)</td>
<td>Energy produced locally</td>
</tr>
<tr>
<td>IT</td>
<td>Cooling</td>
</tr>
<tr>
<td>CADE</td>
<td>CADE</td>
</tr>
<tr>
<td>PUE</td>
<td>PUE</td>
</tr>
<tr>
<td>DCE</td>
<td>DCE</td>
</tr>
<tr>
<td>CPE</td>
<td>CPE</td>
</tr>
<tr>
<td>DCeP</td>
<td>DCeP</td>
</tr>
<tr>
<td>THD</td>
<td>THD</td>
</tr>
<tr>
<td>ERI</td>
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</tr>
<tr>
<td>HRI</td>
<td>HRI</td>
</tr>
<tr>
<td>KPI</td>
<td>KPI</td>
</tr>
<tr>
<td>TUE</td>
<td>TUE</td>
</tr>
</tbody>
</table>

Table 1 Table of DC metrics classification

In the following Table 2, we summarize the results of this task that have been provided into D7.1. It is clear that the amount of KPIs for each variable that needs to be measured is too extensive, and a proper selection needs to be done in order to standardize concepts among the Cluster members and facilitate result sharing and feedback.

<table>
<thead>
<tr>
<th>Energy/power consumptions (load)</th>
<th>Energy produced locally</th>
<th>Heat recovered</th>
<th>Power shifting</th>
<th>CO2 emissions</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT</td>
<td>Cooling</td>
<td>UPS</td>
<td>Transformer</td>
<td>Lighting</td>
<td>Building</td>
</tr>
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<td>DPRE</td>
<td>DPRE</td>
<td>DPRE</td>
<td>DPRE</td>
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<tr>
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</table>

Table 2 Results of Task 1

The main outcome of the Task is a document that gathers a complete list of existing KPIs for measuring energy consumption in DCs, energy produced locally or recovered, adaptation of energy consumption, environmental impact and energy and economic performance. These results have been discussed during the 1st cluster meeting in Barcelona on March 20th 2014 and agreed on some point’s limitations that constitute the result of Task 2.
II.3. Task 2

The goal of this task is to analyze the metrics identified into Task 1 and to determine their limitations and weak points. Indeed, once the existing metrics to measure the different variables were identified, a first analysis to determine limitations is needed in order to develop new metrics. The selected metrics are further investigated and analyzed, including their measuring methodology.

As scheduled into Fig. 1, this task has been completed. In particular the results are summarized in the following statements that have been achieved during the workshop in Barcelona (20th March, 2014):

- There is a huge number of metrics to evaluate a single parameter. For instance, there are more than 30 metrics to evaluate IT power consumption. There is also a lack of standardization (for example, when measuring the efficiency of the DC air-conditioning, there are several metrics and each one does not measure exactly same consumptions).

- To summarize, the Cluster concluded that the existence of different metrics to assess the same parameters creates difficulties to compare the efficiency and environmental footprint between different DCs.

- There is no clear methodology to measure workload performance, i.e. how much useful work can be done, taking into account the different services in a typical DC. Existing metrics don't allow comparing performance results among DCs. Moreover, there is no clear method to normalize performances in different applications and services provided in a DC. The final goal in a mid/long term future would be to define labelling in DCs, although it is out of the scope of Cluster activities.

- Once a KPI is defined, it is necessary to establish how it is measured and the parameters or hypotheses taken into account for the measurement.

II.4. Task 3

Task 3 aims to propose new metrics based on the existing ones that improve metrics’ limitations identified into previous tasks. During the first Cluster’ workshop that took place in Barcelona (on March 20th, 2014), Task 3 was divided into 3 sub-tasks with independent leaders:

1. **Sub-task 3.1:** Choose current metrics for measuring energy/power consumptions selected from existing ones. The main goal of this task is to define KPIs for measuring IT, Cooling, UPS, Transformer, Lightning and Building consumptions. For most of these consumptions KPIs previously developed already exist. This task was led by EATON (Green Data Net).

2. **Sub-task 3.2:** Metrics for measuring use of RES, energy reused and flexibility of DCs to minimize their energy consumptions and environmental footprint. The main goal in this task is to create new metrics or improve the existing ones in order to be able to measure new concepts of energy in DCs, within the context of Smart Cities and Smart Grids. This task was led by GNF (DC4Cities).

3. **Sub-task 3.3:** Metrics for measuring performance in DCs. This Task discusses recently developed concepts about how to measure energy efficiency in DCs and proposes alternatives for the measuring of “useful work” in a DC. This task was led by ENEA (DC4Cities).

The intent of this Task is to provide a view on the selection of current metrics for measuring energy/power consumptions from existing ones (identified in Task 1) and to define new KPIs that complement them and allow the projects to evaluate the achievement of the goals.

This task had a duration of three months, having started in April 2014 and finished in June 2014. The results obtained in Task 3 are summarized in the following paragraphs.
Sub-task 3.1: Results

1. Power Usage Effectiveness: PUE

   Proposed by: Green Grid
   Measures: How much power is used by the IT Equipment in contrast to Facility
   Measuring unit: unit-less (no.)
   Calculation Method:

   \[ PUE = \frac{\text{Total Facility Power}}{\text{IT Equipment Power}} \]

   Four categories of PUE have been defined, PUE\(_0\) being the current category for the first
   PUE definition:

   \[ PUE_0 = \frac{P_{DC} \, [W]}{P_{UPS} \, [W]} = [\emptyset] \]

   To solve inconsistencies and in order to be more specific, different categories of PUE
   were developed. They relate the energy used by the DC with the UPS, PDU and IT
   energy, to be able to make more comparisons between energy usages.

   \[ PUE_1 = \frac{E_{DC} \, [Wh]}{E_{UPS} \, [Wh]} = [\emptyset] \]
   \[ PUE_2 = \frac{E_{DC} \, [Wh]}{E_{PDU} \, [Wh]} = [\emptyset] \]
   \[ PUE_3 = \frac{E_{DC} \, [Wh]}{E_{IT} \, [Wh]} = [\emptyset] \]

2. Renewable Energies Factor: REF

   Proposed by: ETSI
   Measures: REF is an operational Key Performance Indicators corresponding to the use
   of renewable energy. REF is the ratio of local renewable energy over the total data
   centre energy consumption. It is a dimensionless number.
   Measuring unit: unit-less (no.)
   Calculation Method:

   \[ REF = \frac{E_{REN}}{E_{DC}} \]

   Where:
   - \( E_{REN} \) = Measurement of renewable energy (KWh).
   - \( E_{DC} \) = Total of energy consumptions by a data centre over a year (KWh).

3. IT Equipment Energy Efficiency: ITEE

   Proposed by: Green IT Promotion Council
   Measures: ITEE (IT Equipment Energy Efficiency) is an approach to introduce IT
   equipment with higher energy saving performance.
   Measuring unit: unit-less (no.)
Calculation Method:
\[
ITEE = \frac{\text{Total rated capacity of IT equipment (rated in KWh)}}{\text{Total rated power of IT equipment (rated in KWh)}}
\]

4. Energy Reuse Effectiveness: ERE

*Proposed by:* Green Grid

*Measures:* The energy efficiency in data centers that re-use waste energy from their own data center

*Measuring unit:* unit-less (no.)

*Calculation Method:*
\[
ERE = \frac{\text{Cooling} + \text{Power} + \text{Lightning} + \text{IT Energy} - \text{Reuse}}{\text{IT Energy}}
\]

5. Cooling Effectiveness Ratio: CER

This indicator is under discussion at the moment. It definitely makes sense to consider it as cooling is the main energy consumption pool after IT.

**Sub-task 3.2: Results**

In this sub-task new metrics have been proposed in order to measure: the use of RES, energy reused, flexibility of DCs to minimize their energy consumptions and environmental footprint. In detail, these metrics are classified in the following blocks:

1. **Flexibility mechanisms in Data Centres:** adapting the power/energy consumption in Data Centres, by shifting workloads from peak to valley hours/to times when more renewable or waste energy is available/to lower price hours. This can reduce significantly the environmental impact of these consumers and improve their integration in a smart grid, participating in Smart Cities energy optimization initiatives. It will be distinguished between two different flexibility mechanisms:
   - **Demand shifting:** workloads are shifted from a time period to another, but always within the same Data Centre.
   - **Demand being federated:** federation of Data Centres can be a mechanism to optimize the behaviour of DCs from the energy and economic point of view (to increase the usage of renewable or waste energies, for example) shifting the workloads to other Data Centres where more renewable or waste energy/ lower prices are available.

2. **Renewable energy consumption:** maximizing the renewable energy usage can reduce significantly the energy and environmental impact of Data Centres. In previous tasks (Task 1) some metrics have been identified. Nevertheless, they don’t consider some relevant factors that are necessary to evaluate correctly the global impact, as for example, that not only electricity produced locally has to be taken into account, but also the usage of renewable from the grid. Hence, new metrics have been proposed in this task.

3. **Energy recovered:** it refers to the waste energy produced due to the operation of a Data Centre that has the capability of being reused in the same Data Centre or in another close consumer. In this case, there are also several existing metrics that evaluate this parameter. However, some improvements/modifications have been proposed into task 3, defining new metrics.
4. **Primary Energy consumption and CO₂ emissions**, it refers to the total primary energy consumption and emissions of the Data Center.

5. **Economic savings in energy expenses**, how much the energy expenses has been increased/decreased in comparison to a baseline scenario, after having performed actions (improvements in equipment, flexibility mechanisms, etc) to upgrade the energetic, economic or environmental behaviour of a DC.
Since these classifications have been discussed in depth into D7.1 and in the EC report - Cluster Activities Task 3<sup>2</sup>- in the following table we summarize the most important outcomes coming from sub-task 3.2.

<table>
<thead>
<tr>
<th>Classification</th>
<th>METRIC</th>
<th>PROPOSED BY:</th>
<th>FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexibility mechanisms in Data Centers:</td>
<td></td>
<td></td>
<td>a.  Adaptable Curve (APC):</td>
</tr>
<tr>
<td>1. Energy shifting</td>
<td></td>
<td></td>
<td>[APC = 1 - \sum_{i=1}^{n} \left</td>
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<td></td>
<td></td>
<td></td>
<td>[K_{APC} = \sum_{i=1}^{n} \frac{E_{DCi}}{E_{Pi}} ]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>b.  Adaptable Curve (APCren):</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>[APC_{ren} = 1 - \sum_{i=1}^{n} \left</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>[K_{APCren} = \sum_{i=1}^{n} \frac{E_{DCi}}{E_{Ren_i}} ]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>c.  DCAdapt (DCA):                                                                  [CA = 1 - \sum_{i=1}^{n} \frac{</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>[K_{DCA} = \frac{\sum_{i=1}^{n} E_{DCREAL_i}}{\sum_{i=1}^{n} E_{DCBASELINE_i}} ]</td>
</tr>
</tbody>
</table>

### Flexibility mechanisms in Data Centers:

2. Energy being federated

<table>
<thead>
<tr>
<th>a. Federated Energy Weight (FEW);</th>
<th>b. Federated (COP);</th>
<th>c. Federated (RES);</th>
</tr>
</thead>
</table>

#### DC4Cities project (GNF)

<table>
<thead>
<tr>
<th>a. Federated Energy Weight (FEW):</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{FEW} = \sum_{i=1}^{n} \frac{\text{FedE}<em>{DC_i}}{\text{FedE}</em>{DC_i}} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>b. Federated (COP):</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{COP}<em>{\text{federated}} = \frac{\eta</em>{DC_1} \cdot WD_T}{\sum_{i=1}^{n} \eta_{DC_i} \cdot WD_{DC_i}} )</td>
</tr>
<tr>
<td>( WD_T = WD_{DC_1} + WD_{DC_2} + \ldots + WD_{DC_i} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>c. Federated (RES):</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Federated RES} = \frac{\sum_{i=1}^{n} (\text{FedE}<em>{DC_i} \cdot \text{RenPercent}</em>{i,1} - \text{FedE}<em>{DC_i} \cdot \text{RenPercent}</em>{i,2})}{\sum_{i=1}^{n} (\text{FedE}_{DC_i})} )</td>
</tr>
</tbody>
</table>

#### 1. RENEWABLE USAGE:

<table>
<thead>
<tr>
<th>a. RenPercent:</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{RenPercent} )</td>
</tr>
</tbody>
</table>
Renewables integration:  
- Energy produced locally and renewable usage

1. Renewable usage:
   a. RenPercent;
   b. RenEPPercent;
   c. RenThermPercent;
   d. RenEPThermPercent;
   e. TotalEPPercent;

2. REF – Renewable Energies Factor (local RES);

3. Grid interaction indicators.

Indices:
- from a. to d. are proposed by DC4Cities project (GNF);
- e. is proposed by DC4Cities (GNF) & RenewIT (IREC);
- REF is proposed by ETSI;
- Grid interactions indicators are proposed by RenewIT (IREC)

\[
\text{RenPercent} = \frac{\sum_{i=1}^{n}(E_{DC\text{grid}} - E_{DC\text{self-consump}})}{\sum_{i=1}^{n}E_{DC}}
\]

b. RenEPPercent:
\[
\text{RenEPPercent} = \frac{\sum_{i=1}^{n}EP_{renDC}}{\sum_{i=1}^{n}EP_{DC}}
\]

c. RenThermPercent:
\[
\text{RenThermPercent} = \frac{\sum_{i=1}^{n}(Q_{DC\text{DH}} \cdot Q_{renDC} + Q_{DC\text{HTPren}} + Q_{DC\text{self-consump}})}{\sum_{i=1}^{n}Q_{DC}}
\]

d. RenEPThermPercent:
\[
\text{EPRenPercent} = \frac{\sum_{i=1}^{n}Q_{renDC}}{\sum_{i=1}^{n}(EP_{thermal} + EP_{others})}
\]

e. TotalEPPercent:
\[
\text{EPRenPercent} = \frac{\sum_{i=1}^{n}EP_{renDC}}{\sum_{i=1}^{n}EP_{DC}}
\]

2. REF:
\[
\text{REF} = \frac{E_{\text{REN}}}{E_{DC}}
\]

3. GRID INTERACTIONS:
\[
\gamma_{\text{load}} = \frac{\int_{t_1}^{t_2} \min[g(t)c), l(t)]dt}{\int_{t_1}^{t_2} l(t)dt}
\]
### Table 3 New metrics provided by the Cluster

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Formulas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy recovered</td>
<td>• Heat recovered</td>
<td></td>
</tr>
</tbody>
</table>
DC\textsubscript{ReusePercent} = \frac{\sum_{i=1}^{n}(Q_{\text{reused DC}} + Q_{\text{reused outside DC}})}{\sum_{i=1}^{n}(EPE - \text{thermal DC}_i + E\text{Others} - \text{thermal DC}_i)}  
**b. ERE:**  
ERE = (Cooling + Power + Lighting + IT - Reuse \times SourceFactor)/IT |
|                                           | DC\textsubscript{4Cities project (GNF)} & ERE proposed by The Green Grid    |                                                                         |
| Primary energy savings and CO₂ avoided    | a. Primary energy savings: Pe savings; CO₂ avoided emissions: CO₂ savings   |                                                                         |
| avoided emissions                         | DC\textsubscript{4Cities project (GNF)} & IREC (CoolEmAll, RenewIT)        |                                                                         |
|                                           | a. Pe savings:                                                             | **a. Pe savings:**  
P\textsubscript{e savings DC} = \frac{\sum_{i=1}^{n}(EPE\text{DC}_i + E\text{Others DC}_i)_{\text{baseline adjusted}} - (EPE\text{DC}_i + E\text{Others DC}_i)_{\text{current}}}{\sum_{i=1}^{n}(EPE\text{DC}_i + E\text{Others DC}_i)_{\text{baseline adjusted}}}  
**b. CO₂ savings:**  
CO₂\textsubscript{savings DC} = \frac{\sum_{i=1}^{n}(CO₂e\text{DC}_i + CO₂\text{Others DC}_i)_{\text{baseline adjusted}} - (CO₂e\text{DC}_i + CO₂\text{Others DC}_i)_{\text{current}}}{\sum_{i=1}^{n}(CO₂e\text{DC}_i + CO₂\text{Others DC}_i)_{\text{baseline adjusted}}} |
| Economic savings in energy expenses       | • Energy expenses: EES                                                      | **EES =**  
\frac{\sum_{i=1}^{n}((E\text{DC}_i \cdot Cost\text{DC}_i + E\text{others DC}_i \cdot Cost\text{others DC}_i)_{\text{baseline adjusted}} - (E\text{DC}_i \cdot Cost\text{DC}_i + E\text{others DC}_i \cdot Cost\text{others DC}_i)_{\text{current}}}{\sum_{i=1}^{n}(E\text{DC}_i \cdot Cost\text{DC}_i + E\text{others DC}_i \cdot Cost\text{others DC}_i)_{\text{baseline adjusted}}}  
| DC\textsubscript{4Cities project (GNF)}, IREC (CoolEmAll, RenewIT), Eng, SILO, TUC (GEYSER). | **|
Sub-task 3.3: Results

In this Task the new approach to energy performance metrics in DCs developed in the D7.1 and D7.2 of DC4Cities project is presented and discussed with the partners from the Cluster. The discussion within the Cluster has brought so far only minor comments to the methodology that was taken into account in its development.

II.5. Task 4

Task 4 aims to propose a methodology common for all DC projects to measure the defined metrics listed in Task 3; depending on the adoption of each KPI by the different projects (only methodologies for KPIs to be used for at least two projects have been developed, see D7.2 III.1.2 for more details). Task 4 has been led by Synelixis (DOLFIN project), it was divided into two sub-tasks, with the following objectives:

- **Subtask 4.1**: Identify the methodologies for existing KPIs selected in Task 3.1, which essentially will consist of extracting the existing measurement methodologies from the reference documents. Led by UTCR Ireland (project GENiC).

- **Subtask 4.2**: Define methodologies for new KPIs. Methodologies to define how to measure the KPIs defined within Task 3.2 need to be settled in this task. Led by IREC/Loccioni (project RenewIT).

The task was completed in July 2015 as we can see in Figure 2 and the results have been included into D7.2 and in the EC’ report³. The new methodologies developed in Task 4 – for calculating KPIs - are consistent with the International Performance Measurement and Verification Protocol (IPVMP)⁴ and in particular, included:

- Parameters that need to be considered when measuring a KPI and how each of these parameters can influence the KPI result (and therefore how to represent this influence and relate it with the KPI values);
- How and where to measure each variable (scheme including necessary information);
- Frequency of the measures;
- Mathematical approach.

However, in the direction of defining common methodologies for the measurement of common KPIs toward a collective standard development, Task 4 focused on the definition of common measuring and verification methodologies. Specifically, Task 4.1 presented measuring and verification methodologies for existing metrics which are almost finalized by standardization bodies (e.g. ISO/IEC JTC 1/SC 39), using the quasi-finalized metrics as common basis for comparison.

Sub-task 4.1: Results

The purpose of Task 4.1 is to evaluate measurement methodologies for a subset of metrics already presented by the Smart Cities DC Cluster within Task 3 activities (Smart Cities DC Cluster, 2014). Specifically, metrics already defined within the data centre industry were selected for Task 4.1; though some of these defined metrics have a higher rate of adoption than others amongst data centre operators. Additionally, a key selection criterion was the

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relevance of the metric at hand to the objectives and goals of the projects participating within the Cluster.

Hence, the work for this task involved selecting those metrics deemed most suitable for use by the Cluster, evaluating their already existing methodologies, and, where appropriate, improving and extending known methodologies.

To that end, for the following Task 4.1 metrics, PUE, REF, ITEE, CER and ERE, the first three avail of existing work provided by ISO/IEC JTC 1/SC 39, with the methodologies for the remaining one no methodology has been developed by ISO/IEC JTC 1/SC 39. However, for this metric the Cluster has proposed a new methodology.

In the following table we summarize some comments that Cluster has provided in terms of methodology to ISO/IEC JTC 1/SC 39.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Formula</th>
<th>Cluster Amendments to Methodology Adopted by ISO/IEC JTC 1/SC 39</th>
</tr>
</thead>
<tbody>
<tr>
<td>PUE - Power Usage Effectiveness (PUE)</td>
<td>[ PUE = \frac{Total \text{ facility power}}{IT \text{ equipment power}} ]</td>
<td>The Cluster - using ISO/IEC templates through the French Committee - mostly consisting in clarifications on the methodology, has addressed some comments and amendments.</td>
</tr>
<tr>
<td>REF - Renewable Energy Fraction</td>
<td>[ REF = \frac{E_{REN}}{E_{DC}} ]</td>
<td>Some amendments have been proposed to this methodology:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Do not consider Renewable Energy Certificates as renewable consumption, since these can be bought and sold and therefore do not mean that the DC is actually consuming renewable energy, and may pass on the responsibility of adapting consumption to renewable energy availability to others.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• REF must be calculated as a summation of the renewable energy usage in the different time intervals, rather than using aggregated values.</td>
</tr>
<tr>
<td>ERE - Energy Reuse Effectiveness</td>
<td>[ ERE = \frac{(Cooling + Power + Lighting + IT - Reuse \times SourceFactor) \times IT}{IT} ]</td>
<td>The Cluster has proposed a measurement and verification methodology for Energy Reuse Efficiency, since no methodology has been proposed by ISO/IEC JTC 1/SC 39 at the moment.</td>
</tr>
<tr>
<td>CER - Cooling Effectiveness Ratio</td>
<td>The formula for CER is confidential and is under development by SC39.</td>
<td>Some amendments have been proposed to this methodology:</td>
</tr>
</tbody>
</table>

The purpose of Task 4.2 was to define methodologies for new metrics selected by the Smart City Cluster Collaboration during Task 3. Hence, the work for this task involved considering methodologies most suitable for use by the cluster and extending known methodologies.

Task 4.2 aims to provide methodologies for the new metrics selected by the Cluster during sub-task 3.2. The methodologies for new KPIs, cover three categories:

1. Flexibility Mechanisms in Data Centres: Energy Shifting, including metrics such as Adaptability Power Curve (APC), Adaptability Power Curve at Renewable Energies (APC_REN), and Data Centre Adapt (DCA);
2. Energy savings: Primary Energy Savings (PE Savings) metric;
3. CO₂ avoided emissions: CO₂ avoided emissions (CO2 Savings) metric;
4. Economic savings: Energy Expenses (EES) metric;
5. Renewables integration metrics: including Energy produced locally and Renewable usage with the Grid Utilization Factor (GUF) metric.

- **APC**
  Adaptability Power Curve (APC) measures how well a DC has adapted its consumption to a given consumption profile. The formula has been proposed into Table 3.

**Methodology**

The methodology for calculating this KPI assumes the availability of a power plan, which must be compared to actual consumption. This is not a parameter that is measured, but provided by the DC management or other authority. In detail, planned consumption must be scaled to allow comparing the shape of consumption curves without taking into account the total energy consumption. In the formula, the only variable that must be measured is the total energy consumption of the Data Centre for each interval. Consumed energy generally includes all electricity consumption, including grid purchases and on-site generation, and is measured at the common point of delivery (POD).

No baseline is necessary for the calculation of APC, since it is a comparison of planned and actual consumption curves, and not a measure of improvement, although $APC_{REN}$ values can be calculated before and after implementation in order to assess improvement.

### Table 4 Task 4.2 results

<table>
<thead>
<tr>
<th><strong>ITEE - IT Equipment Energy Efficiency</strong></th>
<th><strong>ITEE</strong> = $\frac{\text{Total rated capacity of IT equipment (rated in kW)} \times \text{hours}}{\text{Total rated power of IT equipment (rated in kW) \times \text{hours}}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO/IEC JTC 1/SC 39 are close to finalizing the ITEE metric (ISO/IEC JTC 1/SC 39 ITEE, 2015). After careful consideration, this has been selected as the Cluster methodology for measuring ITEE.</td>
<td></td>
</tr>
</tbody>
</table>
The recommended representative period to be considered to calculate APC is of at least one year, to account for seasonality in workload. In order to correctly compare planned and actual consumption curves, they must have the same granularity, i.e. time intervals must be equivalent. Recommended granularity is up to 15 minutes.

- **APC\_REN**

  Adaptability Power Curve at Renewable Energies (APC\_REN) measures how well has a DC adapted its consumption to a renewable availability curve.

  **Methodology**

  Renewable energy considered in the formula of Table.3 is the sum of onsite renewable generation and the fraction of electricity from renewable sources purchased from the grid according to the electricity mix for every time interval. Only two variables need to be measured in order to calculate APC\_Ren: total energy consumption and renewable energy available, both measured for every time interval and expressed in kWh.

  No baseline identification is necessary, since this KPI does not intend to quantify an improvement, although APC\_REN values can be calculated before and after implementation in order to assess improvement.

  The recommended representative period for which to calculate APC\_REN is of at least one year, to account for seasonality in workload and renewable availability.

  Sampling periods of 15 minutes can be considered a good approach for on-site renewable generation and DC energy consumption.

- **DCA**

  DCAdapt (DCA) measures how much a DC has changed its consumption curve from a baseline situation.

  **Methodology**

  As we can see into DCA formula of Table 3, the only parameter that must be measured is the actual DC energy consumption for each time interval. Baseline consumption (also for each time interval) is drawn from the baseline model and is evaluated through measurements of the DC’s energy consumption in the initial situation.

  Energy consumption by the DC should be generally measured at the point of delivery (POD), and includes both energy from the grid and on-site generation.

  In this case, it is necessary to identify a baseline model, to compare consumption before implementation of measures to consumption that would have taken place if no changes had taken place. In order to determine this baseline scenario, it is necessary to establish typical daily profiles that account for different operating and external conditions (winter/summer, workday/weekend, holidays, workload peaks). The set of daily profiles necessary should be defined individually for every DC depending on its specific conditions.

  As well as a baseline measurement period, a post-implementation measurement period is necessary. To account for seasonality in workload and weather, measurement duration of a full year is recommended for both periods, as one year is enough to provide different workloads and weather conditions, and adjustments could be made in case the year cannot be considered representative. Furthermore, it is neither practical nor cost-efficient to measure for many years. Moreover, operating conditions will surely vary through the years.

  Recommended sampling period will depend on each DC’s working conditions, but in practice a sampling period of 15 minutes has been found to be acceptable.
• **PE Savings**

Primary Energy Savings (PE_Savings) measures the savings regarding the consumption of primary energy, which is energy embodied in a resource that can be found in nature, such as fuel or gravitational potential (hydro).

**Methodology**

As shown in the formula of Table 3, energy consumption considered takes into account energy forms and sources other than electricity, e.g. thermal energy in the form of chilled water from a District Cooling scheme.

Electricity from different sources has different Primary Energy Factors (PEF) (i.e. equivalent amounts of Primary Energy per unit of final (used) energy), therefore must be measured independently. Although the amount and form of energy that reaches the DC and is consumed is the same, the Primary Energy (i.e. energy in a form that is found in nature) is substantially different: grid electricity PEF depends on the electricity mix (the fraction of electricity coming from each source and production method, which have different fuel inputs and conversion efficiencies).

A baseline model must be calculated and will be adjusted to account for external parameters such as outside temperature (which strongly affects cooling needs). Other adjustments might be necessary to account for relevant changes in hardware, management and workload.

Since both the electricity mix and on-site generation are strongly seasonal, it is recommended that both pre- and post- implementation measurement periods take place during a full year, and the PE savings value is calculated accordingly. In many cases it will not be possible to measure baseline parameters during a year, in such situations the baseline scenario will be simulated from a series of representative days chosen or selected by studying electricity mix, renewable generation and workload patterns.

• **CO₂ Savings**

CO₂ Savings measures the avoided CO₂ emissions due to the implementation of changes/improvements in techniques, equipment, or strategies.

**Methodology**

The approach taken to calculate CO₂ Savings is analogous to the calculation of PE Savings explained in the previous subsection.

• **EES**

Economic Expenses Savings (EES) quantifies avoided expenses due to the implementation of changes/improvements in techniques, equipment, or strategies.

**Methodology**

Two approaches are possible for calculating EES. The simplest one corresponds to ignoring fixed costs corresponding to amortization and maintenance. EES becomes a useful KPI to assess savings considering operation costs only, whenever the local source is already installed. This is generally the correct approach for Demand Side Management (DSM) projects such as DC4Cities. In such situations fixed costs will take place regardless of operation and therefore must not be considered.

A more complex approach is possible by internalizing the aforementioned fixed costs in the value for energy cost. Considering TCO as energy cost, the profitability of installing local generation can be assessed.

Variables to be measured are energy purchased from the grid and energy consumed from on-site generation, including all forms of energy (electricity and fuels).
In order to calculate EES it is necessary to compare actual/current expenses to those expenses that would have taken place if no actions had been carried out. These are drawn from a baseline model that must be elaborated using data from a representative period, generally one year.

EES is generally calculated for a period of one year, to account for seasonality and variability in weather conditions and workload.

Data collection granularity of 1 hour is generally an acceptable approach, but other frequencies may also be appropriate depending on the case. The key is that data is acquired for each pricing period.

- **GUF**

Grid Utilization Factor (GUF) measures the fraction of time that the DC has to purchase energy from the grid.

**Methodology**

GUF provides a value regarding a specific time period (for which measurements are taken), and therefore is not a comparison between two periods to assess improvement; hence no baseline model is necessary. Data regarding workload, weather conditions, and DC hardware and operation data is necessary to identify said model.

In order to acquire the necessary data, three parameters need to be monitored: electricity exported to the grid, electricity imported from the grid and the portion of time in which net exported electricity is negative.

Due to seasonality in renewable production and DC workload, it is recommended that GUF is calculated for a period of 1 year.

Maximum recommended sampling period for energy consumption and generation is 15 minutes.

### II.6. Task 5

Task 5 is the dissemination of Cluster results to foster the adoption of selected metrics and methodologies as standard for DC energetic, environmental and economic assessment.

A dissemination plan has been elaborated by the Cluster to increase visibility of the works carried out regarding metrics, methodologies and experimental results. Specifically, the Cluster intends to promote standardization of Cluster results, raise awareness among research communities to encourage further research in the related fields, inform the DC community of the benefits of using proposed metrics, and collect feedback from relevant stakeholders that can be used to improve the developments of the different tasks.

The plan identifies a series of stakeholders concerned with the Cluster’s field of work, and establishes a series of channels through which the different stakeholders can be addressed. Furthermore, it includes an initial list of specific organisms, events and publications that could be contacted for participation. Main target stakeholders include standardization bodies, researchers in relevant areas, academic and educational institutions, private industrial companies and professionals in the IT and energy sectors, public administrations and policy-makers.

Regarding standardization bodies, they are a key stakeholder regarding the Cluster’s works, since they are in charge of developing or selecting KPIs and methodologies that become standard (i.e. officially recognized, referential and widely used amongst DC-related projects).

The Cluster is making efforts to give visibility to the cluster works in this framework and has established a regular collaboration with standardization bodies to share the results obtained of
the KPIs and methodologies developed by the Cluster, aiming to facilitate the standardisation of energetic, environmental and economic KPIs for DCs.

On the one hand, the cluster has established an official liaison with ISO/IEC JTC 1/SC 39 “Sustainability for and by Information Technology through an official representative. On the other hand, the Cluster has participated participated (directly or indirectly through a representative) in standardization bodies’ events such as workshops and meetings, as e.g. the CEN/CENELEC/ETSI European Coordination Group on Green Data Centres (CG GDC).

Concerning the dissemination channels, a series of possible dissemination channels have been selected by the Cluster as most useful, always depending on the type and depth of information, and the target audience:

- Scientific publications: workshops, conferences and journals
- Academic events
- Industrial conferences
- Internal dissemination activities
- Online activities through partner projects (web presence, social media, promotional videos)
- Collaboration with academic communities and educational organizations for teaching purposes
- Miscellaneous: brochures, posters, press releases

Although dissemination activities and collaboration with standardisation bodies have been carried out since the beginning of cluster activities, this task has been intensified since May 2015, when the dissemination plan was developed and metrics and methodologies were available. This task is led by EURECA and is a continuous task, which is performed in parallel with other cluster activities.

A more detailed summary of the dissemination plan can be found in D7.2.
## II.6.1. Dissemination activities

A list of completed and planned dissemination activities has been elaborated based on the available information provided the Cluster partner projects.

### II.6.1.a. Publications

<table>
<thead>
<tr>
<th>nº</th>
<th>Project</th>
<th>Partner</th>
<th>Date</th>
<th>Journal/Conference/Workshop/Other</th>
<th>Planned/Submitted/Accepted</th>
<th>Full reference: Authors, title, journal or workshop (with location), date of (possible) publication, publisher</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RenewIT</td>
<td>451</td>
<td>27/06/2014</td>
<td>451 Research website (<a href="http://www.451research.com">www.451research.com</a>)</td>
<td>PUBLISHED</td>
<td>EU datacentre project work together for energy efficiency research</td>
</tr>
<tr>
<td>2</td>
<td>RenewIT</td>
<td>451</td>
<td>28/04/2015</td>
<td>451 Research website (<a href="http://www.451research.com">www.451research.com</a>)</td>
<td>PUBLISHED</td>
<td>Energizing Renewable Datacenters</td>
</tr>
<tr>
<td>5</td>
<td>GENiC</td>
<td>UTRC (with other cluster projects)</td>
<td>6-10/12/2015</td>
<td>Workshop</td>
<td>Accepted</td>
<td>J. Townley &quot;Metrics for Assessing Flexibility and Sustainability of Next Generation Data Centres&quot;, IEEE International Workshop on Green Standardization and Industry Issues for ICT and Relevant Technologies in GlobeCom 2015</td>
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<tr>
<td>6</td>
<td>EURECA</td>
<td>maki</td>
<td>03/10/2016</td>
<td>EcoBalance Conference, Kyoto, Japan</td>
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<td></td>
<td></td>
<td></td>
<td>Submitted</td>
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<tr>
<td>7</td>
<td>DOLFIN</td>
<td>SYN, PSNC</td>
<td>Dec. 2015</td>
<td>IEEE Global Communications Conference (GLOBECOM 2015), The First IEEE International Workshop on Green Standardizations and Industry Issues for ICT and Relevant Technologies (GSICT)</td>
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<tr>
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<td></td>
<td>Presented</td>
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<tr>
<td>8</td>
<td>GENIC</td>
<td>ATOS/CIT/UTRC</td>
<td>22-25/05/2016</td>
<td>Workshop</td>
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<td>Accepted</td>
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<td>Lara Lopez, Enric Pages, Dhanaraja Kasinathan, Jacinta Townley, Dirk Pesch, Susan Rea “Optimizing energy efficiency for next-gen data centres”, Sustainable energy for Data Centres Workshop, CLIMA 2016, Aalborg, Denmark</td>
<td></td>
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<tr>
<td>8</td>
<td>GENIC</td>
<td>TUE</td>
<td>22-25/05/2016</td>
<td>Workshop</td>
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<td>Vojtech Zavrel, J. Ignacio Torrens, Jan L.M. Hensen “Simulation based-assessment of Thermal aware computation of a bespoke data centre”, Sustainable energy for Data Centres Workshop, CLIMA 2016, Aalborg (Denmark), Easychair</td>
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<td>A.Oleksiak, W. Piątek, K. Kuczyński, F. Sidorski, “Controlling energy consumption of a data centre using renewabe energy sources and energy storage”</td>
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Table 5 Cluster’s publications
## II.6.1.b. Talks/Presentations/Events

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<th>Project</th>
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<th>Title</th>
<th>Name of presenter</th>
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<td>DC4Cities</td>
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<td>Cluster presentation</td>
<td>Milagros Rey</td>
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<td>451</td>
<td>08/07/2014</td>
<td>Energising renewable-powered datacentres</td>
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<td>Datacentre Transformation Conference</td>
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<td>Green Grid Forum, San Francisco, US</td>
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<td>GEYSER</td>
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<td>15/10/2014</td>
<td>&quot;GEYSER: Datacentres as prosumers cooperating in an urban energy marketplace&quot; including 2 slides on cluster background and activities</td>
<td>Vasiliki Georgiadou</td>
<td>Amsterdam, NL</td>
<td>DCD Converged; Data Centre Industry</td>
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<td>Eaton - ICTroom</td>
<td>28/10/2014</td>
<td>Data Center World conference in Frankfurt</td>
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<td>&quot;Datacentres as prosumers in an urban energy marketplace&quot; including 2 slides on cluster background and activities</td>
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<td>&quot;Datacentres as prosumers in an urban energy marketplace&quot; including 2 slides on cluster background and activities</td>
<td>Vasiliki Georgiadou</td>
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<td>Data Center Cooling Question Time, FP7-SMARTCITIES Cluster work was mentioned in one of talks and UTRCI discussed the GENiC project, along with the cluster work, with experts throughout the day</td>
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<td>451</td>
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<td>10/11/2015</td>
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<td></td>
<td>Renewable energy panel discussion</td>
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<tr>
<td></td>
<td>Andrew Donoghue</td>
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<tr>
<td></td>
<td>Uptime Institute, Network Meeting UK</td>
<td></td>
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<tr>
<td></td>
<td>DC operators, DCT suppliers</td>
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<tr>
<td>#</td>
<td>Organiser</td>
<td>Company</td>
<td>Date</td>
<td>Topic</td>
<td>Presenter</td>
<td>Location/Address</td>
<td>Audience</td>
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</tr>
<tr>
<td>30</td>
<td>EURECA</td>
<td>Certios</td>
<td>17/11/2015</td>
<td>IT Room Infra - on EURECA</td>
<td>Dr. Dirk Harryvan</td>
<td>Congrescentrum Brabanthallen, Oude Engelenseweg 1, 5222 AA 's-Hertogenbosch, Nederland</td>
<td>End users, IT experts</td>
</tr>
<tr>
<td>31</td>
<td>EURECA</td>
<td>Certios</td>
<td>18/11/2015</td>
<td>DCD London - Introduction EURECA</td>
<td>Frank Verhagen MSc. CDCEP</td>
<td>Excel - London</td>
<td>End users, IT experts</td>
</tr>
<tr>
<td>32</td>
<td>GEYSER</td>
<td>GIT</td>
<td>19/11/2015</td>
<td>&quot;Urban Data Centres as Energy Prosumers in Smart Cities&quot; including a slide on cluster activities</td>
<td>Vasiliki Georgiadou</td>
<td>London, UK</td>
<td>DCD Converged Europe</td>
</tr>
<tr>
<td>33</td>
<td>GreenDataNet</td>
<td>Eaton</td>
<td>24/11/2015</td>
<td>Alliance innovation conference in Lausanne</td>
<td>Fabrice Roudet</td>
<td>Lausanne, Switzerland</td>
<td>Industry</td>
</tr>
<tr>
<td>34</td>
<td>GreenDataNet</td>
<td>Eaton</td>
<td>03/12/2015</td>
<td>Conference: GSmag event in Paris</td>
<td>Stéphane Levillain</td>
<td>Paris, France</td>
<td>Industry</td>
</tr>
<tr>
<td>35</td>
<td>Eureca</td>
<td>Carbon3IT Ltd</td>
<td>18/12/2015</td>
<td>Data Centre Converged London 18th Dec 2015</td>
<td>John Booth</td>
<td>Manchester</td>
<td>20</td>
</tr>
<tr>
<td>36</td>
<td>Eureca</td>
<td>Carbon3IT Ltd</td>
<td>Various (3)</td>
<td>BSI IST 46. 3 meetings in 2015</td>
<td>John Booth</td>
<td>Chiswick, London</td>
<td>4 at each meeting</td>
</tr>
<tr>
<td>37</td>
<td>RenewIT</td>
<td>451</td>
<td>15/01/2016</td>
<td>Energising renewable-powered datacentres</td>
<td>Andrew Donoghue</td>
<td>Data Centre North, Manchester</td>
<td>DC operators, DCT suppliers</td>
</tr>
<tr>
<td>38</td>
<td>Eureca</td>
<td>Carbon3IT Ltd</td>
<td>01/02/2016</td>
<td>Noord Group Infrastructure Conference Feb 2016</td>
<td>John Booth</td>
<td>Oxford</td>
<td>50</td>
</tr>
<tr>
<td>39</td>
<td>Eureca</td>
<td>Carbon3IT Ltd</td>
<td>10/02/2016</td>
<td>Data Centres North 10th Feb 2016</td>
<td>John Booth</td>
<td>Manchester</td>
<td>24</td>
</tr>
<tr>
<td>№</td>
<td>Project</td>
<td>Partner</td>
<td>Date</td>
<td>Event</td>
<td>Title</td>
<td>Location</td>
<td>Aim of the event</td>
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</tr>
<tr>
<td>1</td>
<td>GENIC</td>
<td>CIT</td>
<td>05/01/2014</td>
<td>Workshop on Computing &amp; Environment, &quot;Discussion relating to the polluting impact ICT has on the environment as part of this CIT (S. Rea) discussed our activities including that of the GENIC project in relation to energy management in smart environments.&quot;</td>
<td>Dr Susan Rea</td>
<td>Cork, Ireland</td>
<td>Students and staff of Cork Institute of Technology</td>
</tr>
<tr>
<td>2</td>
<td>GENIC</td>
<td>UTRC-I</td>
<td>2014-04-04</td>
<td>CloudWATCH Cloud Computing Concertation Meeting in Brussels, 29th September 2014 to promote GENIC and to contribute to future research projects in the field of Cloud Computing, by providing our expertise and knowledge in the field of data centre software and energy optimization from a holistic view</td>
<td>Dr Beth Massey</td>
<td>Brussels</td>
<td>Concertation meeting audience</td>
</tr>
</tbody>
</table>

(*) This event is being organized within the Cluster, although it is scheduled for after the end of DC4Cities.

Table 6 Cluster’ dissemination activities (1)

II.6.1.c. Organized events
<table>
<thead>
<tr>
<th>#</th>
<th>GENiC</th>
<th>UTRC-I</th>
<th>Date</th>
<th>Event Description</th>
<th>Organizer/Location</th>
<th>Industry/Participation</th>
<th>GENiC</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>GENiC</td>
<td>UTRC-I</td>
<td>4th April 2014</td>
<td>Meeting with Royal HaskoningDHV consultancy firm in Nijmegen, Holland, 4th April 2014 to discuss data centre modelling</td>
<td>Dr M. Cychowski, Mijmegen, Holland</td>
<td>Industry partner</td>
<td>GENiC</td>
</tr>
<tr>
<td>4</td>
<td>GEYSER</td>
<td>GIT</td>
<td>08/06/2015</td>
<td>GIT participant meeting (internal event)</td>
<td>Report on cluster activities, Amsterdam, NL</td>
<td>Bi-annual report</td>
<td>GIT participants (data centre industry, energy companies and academia)</td>
</tr>
<tr>
<td>6</td>
<td>DC4 Cities</td>
<td>FM, GN</td>
<td>09/09/2015</td>
<td>Workshop</td>
<td>New Key Performance Indicators for evaluating DC sustainability, Copenhagen, DK</td>
<td>Disseminate cluster activities, create awareness on energy KPIs</td>
<td>Researchers, industry representatives</td>
</tr>
<tr>
<td>8</td>
<td>DOLFIN</td>
<td>SYN</td>
<td>16/11/2015</td>
<td>TECHNICAL WORKING GROUP FOR THE EMAS SECTORAL REFERENCE DOCUMENT ON BEST ENVIRONMENTAL MANAGEMENT PRACTICES FOR THE TELECOMMUNICATIONS AND ICT SERVICES SECTOR</td>
<td>Kick-Off Meeting, Brussels, BE</td>
<td>Define the best practices and means of measurement wrt environmental friendliness of Data Centres in the EU</td>
<td>DC owners, DC providers</td>
</tr>
<tr>
<td>9</td>
<td>GENiC</td>
<td>CIT/UCC/IBM</td>
<td>7 - 10 December 2015</td>
<td>First International Workshop on Sustainable Data Centres and Cloud Computing (SD3C)</td>
<td><a href="http://www.zurich.ibm.com/sd3c/">http://www.zurich.ibm.com/sd3c/</a>, Limassol, Cyprus</td>
<td>To bring together researchers and practitioners working on energy efficient and sustainable data centres and cloud computing to exchange views, ideas and discussions</td>
<td>Researchers and practitioners from industry</td>
</tr>
</tbody>
</table>
### Table 7 Cluster’ dissemination activities (2)

<table>
<thead>
<tr>
<th>Nº</th>
<th>Project</th>
<th>Partner</th>
<th>Date</th>
<th>Type of activity / Description</th>
<th>Type / Size of audience</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>EUR ECA</td>
<td>Certios</td>
<td>29/02/2016</td>
<td>Workshop</td>
<td>Public sector</td>
</tr>
<tr>
<td>11</td>
<td>GENiC</td>
<td>ATOS/CIT/UTRIC/Tue</td>
<td>22-25/05/2016</td>
<td>Topical Session (related to event 36)</td>
<td>DC Owners and Operators</td>
</tr>
<tr>
<td>12</td>
<td>GENiC</td>
<td>ATOS</td>
<td>13-17/06/2016</td>
<td>Panel discussion (related to event 37)</td>
<td>Industry</td>
</tr>
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</table>

**II.6.1.d. Other dissemination activities**

<table>
<thead>
<tr>
<th>Nº</th>
<th>Project</th>
<th>Partner</th>
<th>Date</th>
<th>Type of activity / Description</th>
<th>Type / Size of audience</th>
</tr>
</thead>
</table>

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Project Nº 609304  
March 2016
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</thead>
<tbody>
<tr>
<td>7</td>
<td>EURECA</td>
<td>UEL, DCA</td>
<td>02/06/2015</td>
<td>Engage visitors in Datacloud Europe</td>
<td>Data centre executives, 1800 people, 50 stand visitors</td>
</tr>
<tr>
<td>8</td>
<td>GENIC</td>
<td>CIT</td>
<td>06/07/2015</td>
<td>Magazine Article - online: Silicon Republic - CIT engineer looks to get systems talking, <a href="http://www.siliconrepublic.com/innovation/item/36133-wit2014">http://www.siliconrepublic.com/innovation/item/36133-wit2014</a></td>
<td>&gt;25,000 readers of website daily</td>
</tr>
<tr>
<td>10</td>
<td>EURECA</td>
<td>UEL</td>
<td>20/10/2015</td>
<td>Attended ICT Lisbon and identified potential EURECA pilots in Lisbon and Sweden</td>
<td>Researchers, public sector, SMEs, Enterprises, etc.</td>
</tr>
<tr>
<td>11</td>
<td>EURECA</td>
<td>UEL</td>
<td>16/11/2015</td>
<td>EMAS TWG Meeting in brussels</td>
<td>DC Experts</td>
</tr>
<tr>
<td>13</td>
<td>EURECA</td>
<td>UEL</td>
<td>08/02/2016</td>
<td>Engaged with CIVITTA for adopting EURECA tool</td>
<td>Public sector in Baltic Region served by CIVITTA</td>
</tr>
<tr>
<td>14</td>
<td>EURECA</td>
<td>maki</td>
<td>21/04/2016</td>
<td>Invited Advisory Board member for the German EPA (UBA) commissioned project KP14DCE, further developing criteria for environmental sound Data Centres, as contribution/evidence for further development of the German Type I Ecolabel &quot;Blue Public administration representatives on Federal level, Advisory Panel members from Government/Research/Industry/NGO, etc.</td>
<td></td>
</tr>
</tbody>
</table>
| No. | EURECA | Event/Activity | Date | Description | Project consortium partners

| 15 | EURECA | Certios | 2015/2016 | Twitter: Tweets on meetings, retweets of other tweets | Network of followers

| 16 | EURECA | maki | 2016-05-NN | Presentation/workshop on EURECA and public procurement of environmentally sound data centres and data centre services at the Bavarian Chamber of Commerce (IHK) in Munich. To be confirmed. | 30-40 regional level public sector procurers

Table 8 Cluster’ dissemination activities (3)
II.6.2. Interactions with Standardization Bodies

As aforementioned, Standardization Bodies have been identified by the Cluster as the key stakeholder to engage in order to promote the adoption of Cluster KPIs and methodologies as standard practice for DC and project assessment. Therefore, collaboration with these organisms is especially important. An official liaison has been established with one of them, ISO/IEC JTC 1/SC 39 “Sustainability for and by Information Technology”.

<table>
<thead>
<tr>
<th>Location, Date</th>
<th>Event and participation</th>
<th>Participant</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK, Continuous</td>
<td>ISO SC39 / BSI ST/46 - Sustainability for and by IT committee</td>
<td>Rabih Bashroush (EURECA)</td>
</tr>
<tr>
<td>UK, Continuous</td>
<td>ISO SC39 / BSI ST/46 - Sustainability for and by IT committee</td>
<td>Mark Acton (EURECA)</td>
</tr>
<tr>
<td>Brussels, April 1st, 2014</td>
<td>EC-organized workshop &quot;Green Data Centres: Policy measures, metrics and methodologies. Presentation of Task 1 results</td>
<td>Fabrice Roudet Ph. D. (GreenDataNet)</td>
</tr>
<tr>
<td>Frankfurt, Sep 9th, 2014</td>
<td>Physical meeting with CEN/CENELEC/ETSI European Coordination Group on Green Data Centres (CG GDC) secretary Thomas H. Wegmann.</td>
<td>Milagros Rey, Ph. D. (DC4Cities)</td>
</tr>
<tr>
<td>Brussels, November 1st, 2014</td>
<td>M462 Brussels</td>
<td>Nicolas Samman (GreenDataNet)</td>
</tr>
<tr>
<td>Brussels, December 1st, 2014</td>
<td>CG/GDC Brussels</td>
<td>Nicolas Samman (GreenDataNet)</td>
</tr>
<tr>
<td>Paris, March 1st, 2015</td>
<td>CN 39 Paris</td>
<td>Nicolas Samman (GreenDataNet)</td>
</tr>
<tr>
<td>Paris, May 1st, 2015</td>
<td>CG/GDC Paris</td>
<td>Nicolas Samman (GreenDataNet)</td>
</tr>
<tr>
<td>Paris, June 1st, 2015</td>
<td>SC39</td>
<td>Nicolas Samman (GreenDataNet)</td>
</tr>
<tr>
<td>Frankfurt, June 10th, 2015</td>
<td>SC39</td>
<td>Nicolas Samman (GreenDataNet)</td>
</tr>
</tbody>
</table>
II.7. Task 6

II.7.1. Description of activities

Task 6 aims at sharing experiences in the utilization of metrics and methodologies between projects and refining the developments from Tasks 3 and 4 (metrics and methodologies), which will result in updated version of the corresponding Cluster documents. The following figure summarizes the steps agreed by all projects.
Initially this task was planned to be started in November 2015, when all the projects had run at least one month their trials and first results were available. However, finally it was accorded to delay it until the beginning 2016, since not enough data was already gathered by all projects. A physical meeting took place on 4th March, with the objective of launching this task. This task will be led by EURECA and will follow the approach summarized below that was agreed on the physical meeting:

- Gather data from trials and evaluate current formulas and methodologies: each project will summarize the main experiences collected in the trials, providing the following information:
  - Brief description of the trial environment.
  - Evaluation of each KPI, taking into account the following features: comprehensible, easy to measure and to compute, consistency and usage for comparability between DCs.
  - Proposal for improving KPIs formulas and methodologies, if applicable.
  - Presentation of the most relevant results obtained.

- Share results and lessons learnt: the task leader will evaluate data and a workshop will be organized for sharing the experiences and deciding the improvements to apply to metrics and methodologies. This is planned to be organized at the end of June 2016.

- Publish upgrade formulas and methodologies: after the workshop, once the main conclusions are available, the task leader will be in charge of updating the previous cluster documents, adding the changes agreed by all the projects. This task is planned to be finalized in September 2016.

II.7.2. Experiences in the use of metrics in DC4Cities’ trials

In this section, the measuring and verification of new metrics and methodologies defined by the Cluster in the case of DC4Cities trials is presented. In particular, taking into account the Table 3 in this manuscript and the D2.3, D6.2 and D6.3 reports, in this section we provide a summarization of the results in terms of the experiences occurred in Phase I and Phase II trials. The main results of this analysis were presented to the cluster the 4th March, as DC4Cities’ contribution for the development of Task 6.

**Metrics.** As mentioned in the previous deliverables, within the Cluster, metrics and methodologies were classified in two different groups: the existing metrics and the new metrics proposed by Cluster’s members. However, DC4Cities has selected only a subset of these metrics to be evaluated during its trials. In the DC4Cities project the metrics were implemented in an Energy Management System (EMS) namely ENERGIS (see D6.2) and the computation of these metrics was done through this tool. In particular, during the phase I, ENERGIS has considered a set of metrics different with respect to the phase II, when the methodology for all KPIs was already available.

In DC4Cities project, some of the existing metrics have not been used into the trials. In particular the metrics ITEE, ERE, and CER are not used while, PUE was only used as an input parameter. Therefore, no assessment has been performed. Regarding the REF metric, which measures the share of energy coming from renewable source from the total DC energy consumption, DC4Cities measures this concept through the metric RenPercent. Conceptually, both metrics are equivalent. However, REF is a metric that is being standardised, but the methodology currently proposed is not aligned with the metric that DC4Cities needed for evaluating improvements derived from the project. Hence, the REF metric is the equivalent to RenPercent within DC4Cities project and was used in both, phase I and phase II.

Regarding the new metrics (Task 3.2 of Cluster’s documents) in the following we provide a summary of their use into DC4Cities project:
1. Flexibility and Federation metrics:
   - APC: was used in both phase I and phase II.
   - DCA: was used in both phase I and phase II.
   - Federation metrics: there was no federation in phase I. For phase II, FEW, FCOP, FRES were not used. Discarded, other KPIs more adapted for extracting conclusions of trials were suggested within D2.3. For more details, see section III.1.

2. Renewables integration metrics:
   - RenPercent: As aforementioned, conceptually RenPercent is equivalent to REF metric, but with a slightly different methodology. This metric was used in both phase I and phase II.

3. Environmental metrics (PE savings, CO2 savings): these KPIs were partially tested in phase I and used in phase II. Savings in final energy terms, were also assessed.

4. Economic savings: EES, this KPI was partially tested in phase I and used in phase II.

5. Capacity management & planning: these metrics were not used in DC4Cities.

6. Grid interaction indicators: these KPIs were not used in DC4Cities.

Methodology. In DC4Cities’ trials a common measurement and verification (M&V) plan according to the Cluster’ framework has been used. In detail, the M&V methodologies defined in Task 4 are compliant with the International Performance Measurement and Verification Protocol (IPMVP). The IPMVP is a protocol developed by a consortium of international organizations, defining standards for energy efficiency projects. Capitalizing on the success of IPMVP, Task 4 determines measuring and verification methodologies fully in line with the successful and pervasive methodologies of IPMVP, giving rise to a coherent Cluster protocol, allowing for the efficient comparison of Cluster projects and the exploitation of registered measurements toward amalgamation of feedback and the emergence of a holistic approach allowing the drawing of common Cluster conclusions.

The usage of this methodology, for the three DC4Cities environments has allowed comparing results between different scenarios, being very useful to detect under which external conditions and for which application DC4Cities is more suitable.

Depending on the selected KPI, a comparison from the DC behaviour before (baseline scenario) and after DC4Cities deployment is required. As measurements are not simultaneous, changes in variables that affect the energy consumption from the DC may take place. Those variables are called independent variables in IPMVP protocol. Generally, energy consumption depends on several different variables, which can be internal variables, in the case of a DC e.g. workload of the services or services provided to end customers, and external variables, e.g. outside temperature. In order to avoid that changes in operating conditions or other variables distort the analysis, it is required to adapt baseline scenario to the same operating and external conditions that exist during the project, i.e. KPI calculated in this way will reflect only the improvements due to the project, removing variations in energy consumption due to other factors.

The results regarding the metrics selected for phase I have been used also during phase II and the usage of this common methodology has allowed quantifying the improvements.

After finalising phase I, a first evaluation of the KPIs and methodologies from the DC4Cities perspective was performed. The main results can be found in D2.3. The following sections contain the main conclusions obtained from this previous assessment as well as an updated

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6 In general, savings metrics are very useful to evaluate the impact of a project in different phases:
- Audit phase for the engagement of a DC to launch a project;
- Operation phase to understand actual impact.
assessment considering the experiences gathered within the second phase of DC4Cities trials (see D6.3 for more details).

In order to be consistent with the previous analysis and with the structure for Task 6 agreed at cluster level, besides specific requirements of the metrics from the DC4Cities point of view, a more general analysis is performed considering some general requirements that metric needs to fulfill in case of proposing it as a potential metric to be standardized: a metric must be comprehensible, easy to measure, easy to compute\textsuperscript{7}, representative of what should be measured, consistent and comparable.

II.7.2.a. Existing metrics

RED/ RenPercent (see Cluster activities Task 3) is the KPI selected in replacement of RED for assessing the achievement of the main project’s goal, comparing the coverage of the DC energy consumption by renewable sources before and after implementing DC4Cities.

As shown in the section II.4, the formula used for computing this metric is the following:

\[ \text{RenPercent} = \frac{\sum_{i=1}^{n} E_{\text{DCgrid}}(i) \cdot E_{\text{em}}(i) + E_{\text{DCsel}}(i)}{\sum_{i=1}^{n} E_{\text{DC}}(i)} \]

No changes were implemented in the RenPercent formula in DC4Cities between phase I and phase II.

As aforementioned, the RenPercent within DC4Cities project is equivalent to RED metric; however, there are relevant conceptual differences between RED and RenPercent:

- **RenPercent** does not consider **Renewable Energy Certificates** as renewable consumption, since these can be bought and sold and therefore do not mean that the DC is actually consuming renewable energy, and may pass on the responsibility of adapting consumption to renewable energy availability to others. Instead, it considers **only renewable energy from local sources or purchased directly**, and the fraction of renewable energy consumed according to the instant grid electricity mix (if available).

- **RED** must be calculated as a **summation** of the renewable energy usage in the **different time intervals**, rather than using aggregated values → in a demand response project not to work with aggregated values is key to evaluate improvements.

- Grid electricity mix should be available of intervals of up to one-hour → not very common nowadays.

This metric was selected as the one to be used to evaluate the main goal of the project, the impact in the share of RES used by the trials thanks to the installation of the DC4Cities control components. Then, the KPI needs to be calculated for both the baseline and the trial periods. For the calculation of this KPI, normally no adjustments are required. However, in case local RES are available in the DC during the time “baseline” and time “during trials” adjustments may be required if the impact of DC4Cities control components needs to be independently analysed. It is worth

\textsuperscript{7} Once implemented in an Energy Management System (EMS), metrics are calculated automatically. However, in some cases previous works (e.g. input profiles, baseline) must be developed which can require complex computation using basic tools.
noting that in order to avoid also that variations in %RES of the grid or on-site renewable power plants affect the result and the impact of DC4Cities cannot be correctly assessed, it is supposed that renewables curve in the grid remain constant in baseline and trial scenarios and therefore a representative set of %RES daily profiles have been developed for the trials.

The development of this metric as well as its application in the DC4Cities’ trials showed the following properties:

1. **Comprehensible**: RenPercent is a very intuitive metric and easy to comprehend. It is worth noting that the result is indirectly affected by many external factors, the most important of which is the availability of renewable resources depending upon the DC location. Therefore, in order to interpret it correctly, if the impact of one of the parameters needs to be evaluated, it is required to compare the two situations trying to modify only this factor, as has been done in the trials.

2. **Not easy to measure**:
   - **%RES in the grid**: this variable cannot be measured; it needs to be provided by a third party (energy retailer, smart grid or grid operator, etc). Indeed to provide the %RES in the grid, normally is not available in real-time and needs a post-processing work. But it is essential to consider in a demand response project, if the purpose is to support non-manageable renewable energies integration through demand response mechanisms. Otherwise improvements due to consumption shifting cannot be evaluated.
   - **Local sources**: the supply from rooftop solar cells or other on-site generation can duly be quantified, since normally an independent meter is installed. Therefore, hourly data production from local sources will be normally available and will be easy to obtain with the adequate metering.
   - **IT/global consumption**: easy to obtain and often available.

3. **Easy to compute**: also thanks to the usage of the EMS, ENERGIS, which has simplified the procedure. However, for this case, the impact of using an EMS is lower in comparison to other metrics, since the calculation is not complex with other tools, if the data required is available.

4. **Consistent**: RenPercent will be totally different on a sunny day with respects to a bad weather day. However, this is consistent, since the metric must reflect the share of renewable energies from the total energy consumption. If the impact of modifying the renewable availability was low, the metric would not reflect consistently the concept for what it has been defined.

5. **Comparable**: RenPercent allows comparison between DCs with the same energy supply, e.g. DCs in the same city with no local generation, as was the case of IMI and CSUC DCs in Barcelona for Phase I. It also allows comparing the results after DC4Cities implementation vs the baseline situation. Comparison between DCs with different electricity supplies, however, needs to be carefully taken, since different grids/local RES generation plants provide different baseline situations and influence the actual improvement potential in terms of RenPercent. Like PUE, this metric has dependences on variables that the DC can’t control in the short term and are not affected by DC4Cities.

**Application of RenPercent in DC4Cities**

The following chart shows the results for one of the trial days in CSUC (Barcelona trial). DC4Cities has followed a power curve (blue line) that concentrates energy consumption at times of highest local (green line) and grid RES (cyan line) availability, thus achieving relevant improvements in RenPercent comparing to the baseline situation (yellow line).
RenPercent is calculated from the results for both baseline and trial situations, thus allowing evaluating the improvement due to DC4Cities.

**DC4Cities main conclusions for the cluster**

In the first stages of the Cluster, a big amount of metrics to measure similar concepts was identified as an important barrier for the standardization of metrics, which could be generalised and used by the DC industry. Therefore, from DC4Cities perspective, we would suggest to continue the collaboration with standardisation bodies in order to adapt the current methodology proposed for REF metric, with the objective of defining a more general methodology that can be valid for a broader scope of projects and DCs. This is in line with the approach followed in the development of Tasks 3 and 4 and with previous comments shared with standardisation bodies.

From DC4Cities perspective, REF must be calculated as a summation of the renewable energy usage in the different time intervals (e.g. 15-minute slots), rather than using aggregated values in a net-balance approach. Otherwise, the methodology is not going to be valid for all the cases that may appear, as e.g., in a demand response project, where improvements are based on the consumption pattern adaptation.

Nevertheless, it exists an important barrier, since hourly energy mix real-time data from the grid is normally not available. Therefore, a compromise should be found in order to propose for standardization a methodology that is feasible and can be largely used. If the data is not available or provided by the energy supplier, computations could be done considering typical seasonal profiles that may be developed using hourly electricity mix data published by System Operators (as has been done in DC4Cities). Depending on the country, typical seasonal profiles are also published.
On the other hand, this barrier does not apply to on-site renewable generation, since hourly data is normally available.

II.7.2.b. New metrics

*Flexibility/Federation*

DCA (Data Centre Adaptability) compares the energy consumption profile before and after implementing DC4Cities; this metric measures how much the DC energy profile has shifted from baseline energy consumption after the implementation of flexibility mechanisms. In particular, this KPI compares the shape of actual and baseline consumptions and not their modules (a K parameter to ensure that the area below both curves is the same is included in the definition of this KPI, see formula Table 3), thus making it unnecessary to adjust the baseline for the calculation of DCA.

As shown in the section II.4, the formula used for computing this metric is the following:

$$DCA = 1 - \frac{\sum_{i=1}^{n} |K_{DCA} \cdot E_{DC Real} - E_{DC Baseline}|}{\sum_{i=1}^{n} E_{DC Baseline}}$$

$$K_{DCA} = \frac{\sum_{i=1}^{n} E_{DC Baseline i}}{\sum_{i=1}^{n} E_{DC Real i}}$$

This metric was used in both phase I and phase II. However, this formula respect to phase I (published by the cluster in Task 3 document) was modified/improved in phase II (see the figure 4).

<table>
<thead>
<tr>
<th>Metric</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCA Phase I</td>
<td>$$DCA = 1 - \frac{\sum_{i=1}^{n}</td>
</tr>
<tr>
<td></td>
<td>$$K_{DCA} = \frac{\sum_{i=1}^{n} E_{DC Baseline i}}{\sum_{i=1}^{n} E_{DC Real i}}$$</td>
</tr>
<tr>
<td>DCA Phase II</td>
<td>$$DCA = 1 - \frac{\sum_{i=1}^{n}</td>
</tr>
</tbody>
</table>

Figure 5 DCA' formula modified into DC4Cities

Formula was changed with the aim of having a more intuitive range from 1 (100% similarity between baseline and project, no flexibility) to 0 (0% means a high adaptation).

The experience through tests and trials resulted in the following metric requirement analysis:

1. **Comprehensible:** DCA was not intuitive with the formula used in phase I, since values lower than 0 have been obtained. This has been improved with the adoption of new formula, since the range varies between 1 (no flexibility, curves are identical) to 0 (high flexibility, no similar pattern). Since DCA represents the adaptation, one possibility to make it clearer would be more to have the contrary range 1 (high adaptation) and 0
(low adaptation). From a standalone point of view, this metric just gives partial information, since it only provides information regarding how the consumption profile has been changed. Therefore, in order to interpret the result, a jointly analysis with other metrics, such as RenPercent, is required.

2. **Not easy to measure:** due to the requirement of measuring a complete baseline curve.
   - Hourly data from IT consumption/global consumption. Smart metering is required.
   - Data from baseline must be collected.

3. **Easy to compute:** also thanks to the usage of an EMS, which has simplified the procedure. The calculation is not complex with other tools.

4. **Consistent/Representative:** this metric is useful to understand the degree of adaptation of the IT equipment comparing to the baseline situation.

5. **Comparable:** There are no two fully comparable situations in two DCs: the weather conditions, the infrastructure, the flexibility of customer agreements are all not homogeneous. DCA, however, can be viewed as the result of integrating all these differences into one metric – and thus as a measure of how much effort the management of the DC invested in order to deal with these challenges when trying to adapt to the supply of renewable energy.

### DC4Cities main conclusions for the cluster

DCA is an indicator that must be analyzed qualitatively, and together with other KPIs in order to understand the impact of the assessed project/action. At project level, DC4Cities proposes to modify the DCA formula as explained above, to be included in a new edition of the Cluster documents.

### Flexibility/Federation

**APC** (Adaptability Power Curve) is used to evaluate how well the DC has adapted its consumption to the power plan; the similarity between the DC energy consumption and the energy consumption order that is received taking into account the energy objectives and constraints.

As shown in the section II.4, the formula used for computing this metric is the following:

\[
APC = 1 - \sum_{i=1}^{n} \frac{|E_{DCi} - K_{APC}E_{Pi}|}{E_{DCi}}
\]

\[
K_{APC} = \sum_{i=1}^{n} \frac{E_{DCi}}{E_{Pi}}
\]

APC equal to 1 means that planned and actual consumption has the same profile, i.e., the DC has followed the consumption plan exactly. The more flexibility, the lower or negative the value of the KPI is. On the contrary, when APC is equal to -1 that means the DC consumption has followed a consumption curve extremely different to the order. The lower or negative the value is, the less accuracy the DC has shown. Hence, this KPI compares actual consumption to planned consumption. This means that is not necessary to calculate the baseline neither doing any adjustment. This metric was used in both phase I and phase II. However, this formula (published by the cluster in Task 3 document) was modified/improved in phase II (see the Table 10).
In detail, the formula was changed with the aim of having a more intuitive range from 1 (100% accuracy following the power plan) to 0 (0% accuracy following the power plan).

Analysing APC according to the metric requirement schema results in the following:

1. **Comprehensible**: APC was not intuitive with the formula used in phase I, since values lower than 0 could be obtained. This has been improved with the adoption of new formula, since the range varies between 1 (perfect plan following, curves are identical) to 0 (low accuracy, no similar pattern).

2. **Easy to measure**:
   - Hourly data from IT consumption/global consumption. Smart metering is required.
   - Power planned defined by the DC or an external stakeholder (e.g. utility) has to be collected and stored.

3. **Easy to compute**: also thanks to the usage of an EMS, which has simplified the procedure. The calculation is not complex with other tools, if the data required is available.

4. **Consistent/Representative of % accuracy**: this metric is useful to understand the degree of adaptation of the IT equipment to a new energy policy.

5. **Comparable**: The comparability of APC does not depend on the region or energy provider’s mix of the data centres under consideration, because these differences are already embedded inside the power plan. However, the spread of constraints (technical restrictions and SLAs) over different data centres reduces the actual comparability.

### DC4Cities main conclusions for the cluster

Other metrics to calculate the concept of accuracy in following a specific plan exist (e.g. MAPE, MPE); however the range of possible results can be different. At project level, DC4Cities proposes to modify the APC formula as explained above, to be included in a new edition of the Cluster documents.

**EES** (Economic savings in energy expenses) provides an expression for overall economic savings in energy expenses within a data centre, once a change has been performed (for instance, improvements have been carried out) with regard to its energetic, economic, or environmental management.

As shown in the section II.4, the formula used for computing this metric is the following:
\[ E_{ES} = \frac{\sum_{i=1}^{n}(E_{DC\cdot Cost_{i}} + E_{others\cdot Cost_{i\cdot baseline\ adjusted}}) - (E_{DC\cdot Cost_{i}} + E_{others\cdot Cost_{i\cdot current}})}{\sum_{i=1}^{n}(E_{DC\cdot Cost_{i}} + E_{others\cdot Cost_{i\cdot baseline\ adjusted}})} \]

The expression \textit{current} denotes the total cost of the energy consumed by the data centre in its “final” configuration, measured for a summation of intervals, while \textit{baseline adjusted} denotes the total cost of the energy that would have been consumed by the data centre during the same period, provided that conditions had remained the same as in the baseline scenario. In our trial calculations have been performed at 15-minute granularity using variable prices where applicable. Normally this metric is calculated for a relatively long period, typically 1 year. As already stated in D6.2, the effective trial period was shorter. A methodology was therefore developed to estimate yearly impact through the usage of typical profiles for the whole year. This metric was used in both phase I and phase II without changes. Moreover, if an authority provides external incentives, this needs to be considered to get the complete overview.

Analysing EES according to the metric requirement schema results in the following:

1. **Comprehensible**: EES is a very intuitive metric, quantifies the impact of the project in economic terms.

2. **Not easy to measure**: only if an hourly basis is required and data is not available, due to the requirement of measuring a complete baseline curve → easy at month/year level.
   - Hourly data from IT consumption/global consumption. Smart metering is required.
   - Data from baseline must be collected. Normally baseline is available through monthly invoices. A model has to be developed if data at hourly basis is required.

3. **Not easy to compute** in an appropriate way without the support of an EMS tool unless aggregated values are considered:
   - Adjustments are required in the baseline for a fair comparison, if changes in independent variables are significant.
   - Complexity of calculation depends on energy supply tariffs. If prices vary hourly (variable or dynamic pricing), a baseline-pricing pattern must be developed. This can be complex and resource consuming.

4. **Representative & Comparable**: for the DC in different periods, and also between DCs.

**DC4Cities main conclusions for the cluster**

Significant and coherent results have been obtained in DC4Cities for all trials. EES expresses savings regarding direct energy costs, i.e. costs paid to the energy supplier. However, other concepts such as regulatory tolls, taxes and incomes (for electricity export) could also be taken into account. This is aligned with the more detailed approach also defined within the cluster for EES (see Task 4 document for more details), which includes other related energy costs, such as amortization of local renewable investments. The DC4Cities trials have encompassed penalty systems to foster compliance with a specific RenPercent target, and to enforce the achievement of the Service Level Objective (SLO). The methodology of this KPI could be made more general to include penalties, as they are indirect energy costs: these penalties will ultimately be caused by a decision to consume or not consume a certain amount of energy at a particular time.
An example of how this more EES could be applied in DC4Cities is shown below. This data correspond to one specific day of the CSUC trial, and therefore the results in a full-size DC could probably differ significantly due to possibly less flexibility in some activities.

![Image](image.png)

**Figure 6 CSUC trial results for one day**

The table below shows the EES value that would have been achieved using the current and proposed “generalized” methodology.

<table>
<thead>
<tr>
<th>CSUC Trial example</th>
<th>Baseline</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy cost</td>
<td>2.02 €</td>
<td>0.35 €</td>
</tr>
<tr>
<td><strong>Current EES</strong></td>
<td>83%</td>
<td></td>
</tr>
<tr>
<td>RenPercent Penalty</td>
<td>1.05 €</td>
<td>0 €</td>
</tr>
<tr>
<td>SLO Penalty</td>
<td>0 €</td>
<td>0 €</td>
</tr>
<tr>
<td>Total cost</td>
<td>3.07 €</td>
<td>0.35 €</td>
</tr>
<tr>
<td><strong>“Generalized” EES</strong></td>
<td>89%</td>
<td></td>
</tr>
</tbody>
</table>

Table 11 Generalized EES example

**CO₂ Savings** (CO₂ emissions savings) provides an expression for savings in terms of CO₂ emissions caused by a data centre's energy consumption, also in this case comparing a baseline situation with a “current” situation in which some change, such as energetic or environmental improvements has been introduced.

As shown in the section II.4, the formula used for computing this metric is the following:

$$CO₂ savings_{DC} = \frac{\sum_{i=1}^{n}(CO₂e_{DC,i} + CO₂ others_{DC,i})_{baseline adjusted} - (CO₂e_{DC,i} + CO₂ others_{DC,i})_{current}}{\sum_{i=1}^{n}(CO₂e_{DC,i} + CO₂ others_{DC,i})_{baseline adjusted}}$$

The formula is similar to the one for EES, and also in this case an aggregate value, calculated from hourly value, must be considered. Δt therefore corresponds to a relatively long period (monthly/yearly values).

The general development of this metric as well as its application in the DC4Cities’ trials showed, with respects to the general metric requirements, that:
1. **Comprehensible:** CO2 Savings is a very intuitive metric, quantifies the impact of the project in environmental terms.

2. **Not easy to measure** in those cases where an hourly basis is required and data is not available, due to the requirement of measuring a complete baseline curve → easy at month/year level.
   - Hourly data from IT consumption/global consumption. Smart metering is required.
   - Data from baseline must be collected. Normally baseline is available through monthly invoices. A model has to be developed if data at hourly basis is required.

3. **Not easy to compute** in an appropriate way without the support of an EMS tool:
   - Adjustments are required in the baseline for a fair comparison. An EMS tool like ENERGIS can support also the development of the model for adjustments. This can be complex and resource consuming using other tools.
   - CO2 emission factors for grid electricity are normally provided at year level; therefore, improvements due to load adaptation from grid consumption are not so easy to calculate. A complex analysis from available data from TSO (REE) in Spain was developed to consider variable factors (depending on the grid electricity mix). Moreover, there exist different sources for CO2 factors and not always consistent. The cluster methodology is more generally explained and this metric can be calculated aggregated at year level, month level. Therefore, the published conversion factor published by each Member State could be normally used. This supposes a simplified analysis but still provides relevant results, especially in the case of projects involving energy efficiency and local RES.

4. **Representative & Comparable:** for the DC in different periods, and also between DCs.

**DC4Cities main conclusions for the cluster**

Significant and coherent results have been obtained in DC4Cities for all trials. Trials in Barcelona have used the variable CO2 factor approach, while a simpler analysis has been performed for Milan and Trento trial sites. Assuming a constant factor has provided a more straightforward analysis with valid results.

**PE_Savings** (Primary Energy savings) measures the savings regarding the consumption of Primary Energy, which is energy embodied in a resource that can be found in nature.

As shown in the section II.4, the formula used for computing this metric is the following:

\[
PE_{savings}^{DC} = \frac{\sum_{i=1}^{n}((E_{Pe}^{DC_i} + E_{Others}^{DC_i})_{baseline\ adjusted} - (E_{Pe}^{DC_i} + E_{Others}^{DC_i})_{current})}{\sum_{i=1}^{n}(E_{Pe}^{DC_i} + E_{Others}^{DC_i})_{baseline\ adjusted}}
\]
The structure of the formula is the same as in the other metrics, comparing a “current” and a “baseline” situation, and, also in this case, an aggregate value over a long period of time (1 year) is considered. This metric was used in both phase I and phase II without changes.

The general development of this metric as well as its application in the DC4Cities’ trials showed, with respects to the general metric requirements, that:

1. **Comprehensible**: PE_Savings is a very intuitive metric, quantifies the impact of the project in primary energy terms.

2. **Not easy to measure** in those cases where an hourly basis is required and data is not available, due to the requirement of measuring a complete baseline curve → easy at moth/year level.
   - Hourly data from IT consumption/global consumption. Smart metering is required.
   - Data from baseline must be collected. Normally baseline is available through monthly invoices. A model has to be developed if data at hourly basis is required.

3. **Not easy to compute** in an appropriate way without the support of an EMS tool:
   - Adjustments are required in the baseline for a fair comparison. An EMS tool like ENERGiS can support also the development of the model for adjustments. This can be complex and resource consuming using other tools.
   
   Primary energy factors are normally provided at year level; therefore, improvements due to load adaptation from grid consumption are not so easy to calculate. Moreover, there exist different sources for PE factors and not always consistent. A complex analysis from available data from TSO (REE) in Spain was developed to consider variable factors (depending on the hourly grid electricity mix). The cluster methodology is more generally explained and this metric can be calculated aggregated at year level, month level. Therefore, the published conversion factor published by each Member State could be normally used. This supposes a simplified analysis but still provides relevant results, especially in the case of projects involving energy efficiency and local RES.

4. **Representative & Comparable**: for the DC in different periods, and also between DCs.

**DC4Cities main conclusions for the cluster**

Significant and coherent results have been obtained in DC4Cities for all trials. Trials in Barcelona have used the variable PE factor approach, while a simpler analysis has been performed for Milan and Trento trial sites. Assuming a constant factor has provided a more straightforward analysis with valid results.

Taking into account the formulas in Table 3, a set of variables needed for calculating each KPI (see D3.2, metric catalog) is included:

<table>
<thead>
<tr>
<th>KPI</th>
<th>Metric’s catalog name</th>
<th>Variables required</th>
</tr>
</thead>
<tbody>
<tr>
<td>RenPercent</td>
<td>renewable_energy_percentage (for grid renewable)</td>
<td>IT energy consumption</td>
</tr>
<tr>
<td></td>
<td>renewable_power.actual</td>
<td>DC energy consumption</td>
</tr>
<tr>
<td></td>
<td>power.actual (for local renewables)</td>
<td>Renewable energy supply</td>
</tr>
</tbody>
</table>
In particular, the energy can be calculated in each time interval of 15 minutes, considering no variations in power consumptions during this interval or as an average of the power measurements during this time interval.

Regarding the KPI - *EES, PE_Savings* and *CO_2_Savings*, the following corrections and adjustments were performed:

- Inclusion of PUE in energy consumption to account for all DC consumption, not only IT consumption.
- Normalization of energy consumption to a 24-hour period;
- If necessary, adjustment of energy consumption to take into account the effective quota of work performed during the Trial in those cases where the work performed was significantly different between baseline and trial results.

<table>
<thead>
<tr>
<th>Metric</th>
<th>TRIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RenPercent</strong></td>
<td><strong>HP- EXPERIMENT</strong></td>
</tr>
<tr>
<td></td>
<td>Interesting metric. Improved as expected</td>
</tr>
</tbody>
</table>
## APC (Adaptability Power Curve)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
<th>Changes proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partially interesting metric</td>
<td>Very close to 1, the system is able to execute the plan in a predictable way.</td>
<td>Useful metric to assess the precision of plan following. APC allows comparison between DCs, but the different constraints and particularities of each site must be taken into account. <strong>Changes proposed</strong> Formula from phase I was modified/improved in phase II with the aim of having a more intuitive range of results.</td>
</tr>
</tbody>
</table>

## Data Center Adapt (DCA)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
<th>Changes proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not very interesting metric</td>
<td>The average DCA value was 0.89, which means that the system did not need to be extremely flexible (i.e. change the power profile too much with respect to baseline); in fact also the baseline performance was reasonable (and this is in line with the improvements measured in RenPercent).</td>
<td>To be analyzed jointly with the other KPIs to assess the impact of DC4Cities. Can be used as a qualitative indicator. <strong>II.8. Changes proposed</strong> Formula from phase I was modified/improved in phase II with the aim of having a more intuitive range of results.</td>
</tr>
</tbody>
</table>

## Economic savings in energy expenses

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
<th>Changes proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interesting metric.</td>
<td>As expected, but very small values – but they are correct. Since HP Moonshots consume less than 10% with respect to standard servers, the total power consumption of the 17/19 servers is less than 600W, therefore the cost (and therefore the savings) of energy is very low as absolute value</td>
<td>Intuitive and representative, however it does not include all energy-related expenses considered in the trial. It is difficult to calculate in those cases where an hourly basis is required and data is not available, due to the requirement of measuring a complete baseline curve → easy at month/year level <strong>Changes proposed:</strong> Modify methodology to make it more general, thus including any energy-related costs: rewards, penalties, etc.</td>
</tr>
</tbody>
</table>

---

For example Trento trial reached a REN% improvement of 12.5% on the best day.
II.9. Cluster Conclusion and Next Steps

Up to this date, the main goals of the cluster have been achieved.

Firstly, a set of metrics and methodologies has been developed jointly by the cluster projects and are being used to evaluate project results. All the parameters and KPIs needed by the projects have been addressed within this task. This activity was developed within tasks 1, 2, 3 and 4. These tasks have been completed and results obtained have been published through the EC.

Moreover, the cluster participants consider key the interaction with standardization bodies in order to support the utilization of standardized energy KPIs in DCs. For this reason, an official liaison has been established between ISO/IEC JTC 1/SC 39 “Sustainability for and by Information Technology” and the cluster. Furthermore, the cluster is participating in standardization events, such as regular meetings, where metrics and methodologies can be discussed. This activity is appraised and it is planned to be continued in the following months.

Other stakeholders, such as researchers or IT industry, have been also addressed through the participation in events and workshops.

The next steps of the cluster will be focused on continuing dissemination activities and developing Task 6. Results and experiences from the different projects will be gathered and shared, with the aim of improving the first KPIs and methodologies developed. This task has already been started. DC4Cities contribution has been shared, since the project finalises before the end of the task. The task is already organised and it is planned to prepare a workshop at the end of June 2016, when all the different experiences collected will be discussed and the final KPIs and methodologies will be agreed.
III. ACTIVITIES WITHIN THE PROJECT

III.1. Federation Metrics

III.1.1. Concepts Developed in DC4Cities

In the second phase of the project a set of metrics was developed to grasp the new dimension of the DC4Cities system: federating a DC with other DCs in order to increase the probability of reaching the RenPercent goals. These concepts were laid down in D2.3, chapter 7.3. Here they are shortly summarized:

$\Delta$RenPercent$_{global}$

In consistency with the single RenPercent metric $\Delta$RenPercent$_{global}$ was developed to keep track of the impact of federation on an aggregated RenPercent view. The formula is as follows:

$$\Delta$RenPercent$_{global} = \frac{RenPercent'_{global} - RenPercent_{global}}{RenPercent_{global}}$$

With the following formulas:

<table>
<thead>
<tr>
<th>Data Center</th>
<th>RenPercent</th>
<th>Energy Consump.</th>
<th>Global RenPercent of federated DCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-federation</td>
<td>DC1</td>
<td>RenPercent$_{DC1}$</td>
<td>&lt; Goal</td>
</tr>
<tr>
<td>DC2</td>
<td>RenPercent$_{DC2}$</td>
<td>&lt; Goal</td>
<td>E(DC2)</td>
</tr>
<tr>
<td>Federation</td>
<td>DC1</td>
<td>RenPercent'$_{DC1}$</td>
<td>&gt; Goal</td>
</tr>
<tr>
<td>DC2</td>
<td>RenPercent'$_{DC2}$</td>
<td>&gt; Goal</td>
<td>E'(DC2)</td>
</tr>
</tbody>
</table>

#Escalations avoided

Escalations are a sign of ambitious requirements on the adaptive behavior of the DC and thus of stress on the system. Therefore, escalations avoided through the enactment of a continuous DC federation are a useful metric and can be measured in the following way:

$$Escalations_{Reduced} = Escalations_{NonFed} - Escalations_{Fed}$$

$\Delta$APC$_{global}$

Also for the adaptive power curve APC, the federated point of view enhances the evaluation of the impact of federation on the success of applying DC4Cities: $\Delta$APC$_{global}$ gives account of the aggregated results of all federated DCs adjusting to the normative power curve (be it IPP or CPP) compared to the aggregated results if the DCs had adjusted without assistance of other DCs:

$$\Delta$APC$_{global} = \frac{APC'_{global} - APC_{global}}{APC_{global}}$$

$\Delta$DCEP

DCEP is a metric developed by The Green Grid in order to monitor how the “output” or “work done” of a DC evolves: DCEP means DC energy productivity and contrasts Useful work produced with energy consumption of the whole DC producing this work. The challenge is the definition of a metric for “work done”. On the level of single applications running int two DCs a
unifying metric can be used and thus D CeP compared (in all other cases this metric is not applicable); however, this might be not a very realistic setting, rather a trial setting.

In this approach, D CeP is calculated for the task (not for the DC or the service), which can be relocated or shared among the federated DCs. The formula is the following:

\[
\Delta D\text{CeP} = \frac{\sum_{DC=1}^{n} WD'_DC \cdot D\text{CeP}'_DC - D\text{CeP}_1}{D\text{CeP}_1}
\]

As the task to be carried out does not change, this can be simplified with:

\[
\sum_{DC=1}^{n} WD'_DC = WD_1
\]

In cases where the federation cost or overhead is known, adjustments could be made to this metric to account for the cost.

**GHG Overhead/Savings**

Regarding GHG emissions, the result of federation depends on the kind of RES that were to be increased by applying DC4Cities – and the substituted energy source. Also for public KPIs (e.g. relating to the EU energy 2020 goals), CO_2 or GHG emissions should be captured. The approach is equivalent to most other approaches regarding federation with the exception that in addition to CO_2 federated and non-federated, the CO_2 overhead through the transmission of data is explicitly monitored:

\[
\text{CO}_2\text{savings} = \text{CO}_2\text{ non-fed} - (\text{CO}_2\text{ fed} + \text{CO}_2\text{ overhead})
\]

\[
\text{CO}_2\text{ non-fed} = \sum_{i=1}^{n} \text{E}\text{task}_{1,i}C\text{O}_2\text{coef}_{1,i}
\]

\[
\text{CO}_2\text{ fed} = \sum_{DC=1}^{m} \sum_{i=1}^{n} \text{E}'\text{task}_{DC,i}C\text{O}_2\text{coef}_{DC,i}
\]

And as a percentage value:

\[
\text{CO}_2\text{savingsPercent} = \frac{\text{CO}_2\text{ non-fed} - (\text{CO}_2\text{ fed} + \text{CO}_2\text{ overhead})}{\text{CO}_2\text{ non-fed}}
\]

### III.1.2. Cluster Concept: FederatedRES

FederatedRES was developed in collaboration with the cluster (see D7.1). It is comparable to the DC4Cities RenPercent approach, but consistent with the terminology in the other cluster projects. Whereas ΔRenPercent\text{global} accounts for the relative benefit of federation with regards to RenPercent, FederatedRES accounts for the aggregated RenPercent of the participating DCs compared to an overall federation RenPercent.

\[
\text{Federated RES} = \frac{\sum_{i=1}^{n} (\text{FedE}_{DC_{i}} \cdot \text{RenPercent}_{i,2} - \text{FedE}_{DC_{i}} \cdot \text{RenPercent}_{i,1})}{\sum_{i=1}^{n} (\text{FedE}_{DC_{i}})}
\]

### III.1.3. Applying Federation Metrics in DC4Cities

Phase II of the DC4Cities trials will take place in two phases to evaluate the impact of federation compared to DC4Cities only, as illustrated by the figure below. First, single-site trials will take place independently to test the DC4Cities solution in stand-alone mode. The baseline situation (no energy adaptation) will be the reference scenario for DC4Cities evaluation.

---

8 In case the energy mix is dominated by nuclear power – as in France – the result is not clear!
As can be observed, none of the concepts developed in the course of the theoretical DC4Cities work on metrics could be implemented in the trials, but the metrics used are quite similar.

The trials in DC4Cities all followed the same M&V plan (as laid out in D6.3, see also so that they all used the same metrics, both in phase I (no federation metrics) and phase II (including federation metric). These metrics were implemented and graphically represented in ENERGIS. There were federation scenarios in the trials in Barcelona (CSUC and IMI) and Milano (HP); however, in the Trento trial (CREATE-Net) no federation could be enacted so that the Trento trial is not analysed in the current section.

The metrics monitored in the trials were evaluated alongside four different dimensions:

- Comprehensibility: Is the federation metric easily understood? Does it offer an ambiguous scope of interpretation or are the results straightforward?
- Consistency/Representativeness: Are the results of measurement and computation of the metric consistent and grasp the phenomenon they are intended to represent?
- Measureability: Is the metric easy to measure? Is there a lot of specific equipment necessary to measure them or does measuring generally require too much effort?
- Computability: Given the measurement data – is the computation of the metric feasible with an adequate effort and within given constraints e.g. regarding timeliness of metrics representation.

In phase II the following federation metrics (as described in III.1.1. and III.1.2. ) were monitored in all trials:

**Aggregated CO2**

- Comprehensibility: The aggregated CO2 metric is as easy to understand as the single site metric.
- Consistency: Consistency and representativeness are given.
- Measurability: Measurability depends on the required timeliness of measuring. If monthly or yearly measuring is required, it should be more easy to retrieve the necessary data from the energy data sources than in case of continuous or very frequent measurement times.

It all depends on the data support from external sources – nowadays in many countries CO2 intensity is given on a yearly basis only. A complex analysis from available data from TSO (REE) in Spain was developed. Moreover, there exist different sources for CO2 factors and these are not always consistent with each other. The cluster methodology is more generally explained and this metric can be calculated aggregated at yearly or monthly level.

For a project like DC4Cities, however, this frequency is not good enough. This influences also the creation of baseline curves. For frequent measurement smart metering is required.
• Computability: Computability depends on the quality of the given data. The higher the frequency of given data (see: measurability), the higher the effort for computation. However, computation does not have a high level of complexity.

**Electricity consumption:**

• Comprehensibility: Here the same applies as for federation CO2 savings: the metric can be understood intuitively, as it is the identical concept as for the single site.

• Consistency: Also consistency is not a problem as long as the data quality in all federation sites is good and on the same level.

• Measurability: Measurability is based on installed monitoring equipment. For the trials this was comparable and usable in all sites.

• Computability: Computability is not an issue; as long as data are available, computation is not complex.

**RenPercent'\textsubscript{global}**

\(\Delta\text{RenPercent'}\textsubscript{global}\) has been implemented partly: the weighted shares of federation RenPercent of the individual sites were tracked RenPercent'\textsubscript{global} (see III.1.1.); the comparison between federation and non-federation was not monitored. Therefore apart from the weighting, this metrics is the same as the single site metric so that the evaluation in the context of the single site metric holds.

<table>
<thead>
<tr>
<th>Federation Metric</th>
<th>TRIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HP- EXPERIMENT</td>
</tr>
<tr>
<td>CO\textsuperscript{2}/ENERGY CONSUMPTION</td>
<td>See single site evaluation</td>
</tr>
<tr>
<td>RenPercent'\textsubscript{global}</td>
<td>See single site evaluation</td>
</tr>
</tbody>
</table>

**Table 14 Federation metrics in DC4Cities’ Trials**

**III.2. Further progress on Workload-related metrics**

Recently, several works have been published on workload-reduction techniques - better algorithms and data-structures to improve power/performance [1] - and a few efforts were focused on a better understanding in terms of energy consumption of workload-related metrics to be employed in the operation of a Data Centre.

The general idea is that important benefits in energy efficiency can be achieved by tracking the energy consumption of specific workloads in a DC. To address this issue, this paragraph provides a synthetic review of recent studies carried out on this topic.

As mentioned in the previous public Deliverables - D7.1 and D7.2 - the energy consumption profiles can be evaluated using certain benchmarks. As a matter of fact, so far benchmarks have provided methodologies to evaluate, validate and publish performance results that enable the comparison of different servers and storage solutions. However, even if benchmarks have been used to measure the performance of equipment, they can be adapted to evaluate the energy consumption of workloads. In particular, benchmarks use metrics that take into account performance factors such as data throughput and the energy footprint of workloads.

The following paragraphs shows the progress made on the workload related metrics through:

1. An overview of recently case studies on workload-related metrics using benchmarks procedure (literature reference);
2. introduction of workload-related metrics in HPC systems.
These approaches represent only a step forward on this line of research, which still remains an open challenge, and is quite far from definitive results in terms of energy efficiency in DCs.

### III.2.1. Benchmarks

“Servers are used for many different purposes, and the nature of the software that is run on them, called workload, can have a major impact on the energy use. Those workloads can have a big impact on the productivity and energy use of a server. Benchmarking is a deliberate process of data collection to provide an early indication of how your DC will perform.”

In detail, currently techniques include:

- Running on software stack.
- Running a proxy workload.

In the last case, the results of existing industry benchmarks that measure the server power, and the server power specs, are employed. In particular, the attention focuses on the productivity and energy use; indeed, running the actual workload on the planned server hardware and the software stack is the best way to benchmark in terms of productivity and energy use. To evaluate a stack solution - hardware and software – is a mature approach but it also complicated. For this reason, if you can identify a similar workload that you can run to characterize the solution stack, you can use it as a proxy workload. The use of industry benchmarks can be a research effort in order to provide data and make an approximate prediction of how given solutions stack should perform. However, the current benchmarks cover either productivity or energy but rarely both.

In the following a list of some industry benchmarks is considered:

1. **SPEC**:
   - SPECint_rate is a microprocessor benchmark measuring the throughput of multicore processors on integer calculations. The results are applicable to character **data manipulation** workloads, as those are handled essentially as integer data.
   - SPECfp_rate is a microprocessor benchmark measuring the throughput of multicore processors on floating-point calculations. Historically, the benchmark is also a good indicator of the performance of a server's **memory system**.
   - SPECweb is a system benchmark measuring the **productivity of a web server**.
   - SPECjbb is a system benchmark measuring the **productivity of server-side Java running as a three-tier client–server system**. It highlights the server’s microprocessor, caching and memory subsystem, and multiprocessing while deemphasizing disk and I/O.

2. **Linpack**: is a system benchmark measuring the **productivity of a HPC’ system**.

3. **TPC**: is a system benchmark measuring the productivity of a **server on mission critical, transaction-oriented workloads**, like backend order processing. To get a competitive score requires a huge investment in a large system configuration, so smaller OEMs rarely list results with SPEC.

4. **Stream**: is a system benchmark that characterizes the memory bandwidth of a system. It measures the productivity of **memory-bound workloads** and, by proxy, HPC workloads.

5. **GridMix**: is a system benchmark that characterizes **Big Data and Map/Reduce workloads**.

---

6. **VMmark**: is a system benchmark that characterizes the productivity of virtualized servers consolidated on a common server platform. It has three versions and can incorporate trade-offs among performance, server power, and storage power.

As regards the energy consumption, the most useful information is to measure the energy directly while the server is running the application. Unlike the aforementioned benchmarks, in the following we present a list of benchmarks which are not measures of productivity, but rather measurements of power at different performance levels:

- **SPECpower**—is the first benchmark to assess both server system performance and power. It measures a web server workload running server-side Java (SPECjbb) at every 10% of server full load utilization.

- **SERT**— not a benchmark, but rather an active mode rating tool. The proposed Standard Efficiency Rating Tool is being developed by SPEC for ENERGY STAR. While providing a power, performance, and inlet temperature assessment, it appears to ignore productivity and may exclude dc-input servers.

### III.2.2. Benchmark procedures for Workload Characterization and Related metrics: a study of recent literature

Energy efficiency in computing has historically improved much more slowly than performance or cost\(^\text{10}\). However, it is well-known that in last years power and energy have begun to severely constrain the design of components, systems, and entire DCs. Recently, power has emerged as a critical factor in designing components of storage systems, especially for power-hungry DCs. While there is some research into power-aware storage stack components, there are no systematic studies evaluating each component’s impact separately [12].

In a more recent development, a public memo addresses the agreement reached by the Global Metrics Harmonization Task Force [5] on standard approaches and reporting conventions for DC energy productivity. This document has called on stakeholders to improve DC energy efficiency by identifying effective energy productivity metrics that measure actual IT work output relative to the actual energy consumption.

The DC productivity should be measured by quantifying the “useful work” produced by the DC based on the energy consumed. The useful work output is the operational utilization of the IT equipment and it is left to the user to evaluate and assess the level of usefulness of the IT work output to their business.

In the previous public Deliverable D7.2, the authors have underlined the importance of “workload-related” metrics in measuring the energy efficiency of a DC. These energy performance metrics will facilitate proper energy evaluation and can be used as indicators to rank and classify IT systems and DCs regardless of their size, capacity or physical location.

There has been considerable progress in definition of an energy related metrics for data centres. A general consensus is developing on the fact that the devices directly involved in delivering the ‘useful work’ of the facility, that is the IT equipment, servers, storage, networking and appliances are the energy ‘targets’ and that any other consumption of energy such as power conditioning and distribution or cooling is overhead.

Most of the metrics that have been created and used to measure “work done” or productivity (which must include a metric for “work done” as output) are presented in several manuscripts in the last years (for more detail, see DC4Cities public’ deliverables D7.1&D7.2). Although, a

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\(^{10}\) Belady C. L., February 2007. In the data center, power and cooling costs more than the IT equipment it supports. Electronics Cooling Magazine, 13(1): 24–27.
common methodology in order to calculate this metrics does not exist so far, the advancements have been accomplished through the use of benchmark' procedures.

In this section we provide a series of case studies carried out in several manuscript in which the authors used benchmark' procedures in order to identify and calculate the “useful work”.

### III.2.3. Workload-related metrics

The important question remains how to determine the real cost of DC operations in terms of energy per unit computing. This paragraph tries to answer this questions taking into account the current studies on this topic.

Measurement methods to determine “Energy per computed unit” have yet to be defined and standardized [8]. Part of the difficulty is that there is no standard unit of compute defined. For example, Performance Per Watt (PPW)\(^{11}\) is generally used to describe the energy efficiency of a Computer Processor Unit (CPU):

\[
\text{PPW} = \frac{\text{Performance}}{\text{Power}}
\]

Computing servers account for the major portion of energy consumption of DCs. Ideally, the power consumption of a computing server is proportional to the utilization of the CPU utilization, but in practice this is not always the case. Moreover, an idle server still consumes around two-thirds of the peak-load consumption just to keep memory, disks, and I/O resources running.

In order to take into account the communication part, several studies mistakenly considered the communication network as overhead required only to deliver the tasks to the computing servers\(^{12}\). As a matter of fact communications are at the heart of task execution, and the characteristics of the communication network - such as bandwidth capacity, transmission delay, delay jitter, buffering, loss ratio, and performance of communication protocols - all greatly influence the quality of task execution.

Currently, many researches focus on energy consumption of computing servers and in particular on energy consumption that corresponds to the workload. In summary, one of the open challenges is to determine operational costs for each workload category.

Since each computer component consumes different energy values and since DCs are hosting heterogeneous types of applications each requiring a different combination of system usage, currently, in literature, several studies are presented that are looking at energy efficiency from global perspective where each server has its energy efficiency - compared to one another - based on the type of application running. In the paper of G. Metri et al. [6] the authors define the specific energy consumed by application as:

\[
\frac{\text{Load of the application}}{\text{Energy consumed by the application}}
\]

Where, the load can be different based on the type of application.

This is similar to AWEE, introduced by us in public deliverable D7.1:

---


\[ AWEE = \frac{\text{Work performed by application}}{\text{Energy consumed by the application}} \]

In particular, the authors performed three different kinds of applications:

1. In the case of web applications such as TPC_W (Workload), the load is defined as the throughput;
2. In the case of applications focusing on processing data the load is defined as the size of data processed;
3. In the case of arithmetic operations such as Matrix Stressmark the load is the number of operations, e.g. iterations.

In [6] in order to evaluate the formula the authors created a heterogeneous cloud and ran experiments using different applications (e.g. TPC_W, BS Seeker\(^\text{13}\)...); the goal was to observe how the formula changes based on server type in terms of size, load size, and scaling factor. In the experimental set-up the authors created a real-experiment campaign (e.g. used the Apache Tomcat v. 5.5.20 as application server), a simulated environment using benchmarks (e.g. the Remote Browsing Emulator) and they have adopted an electronic wattmeter to measure the energy consumption. They calculated the energy consumed (of the CPU at low overhead) by calculating the average power consumed during the interval run time of the benchmark:

\[ \text{Energy Consumed} = \text{Average of power} \times \text{Duration of test} \]

Hence, in [6] the authors conducted a large number of experiments to investigate the relationship between application type and energy consumption of servers.

The impact of VM size on the application performance and the energy consumption of the node were the basis of calculating formula to establish a ranking of nodes based on their energy efficiency while running a specific application.

In the work of Arjona et al. [7] the authors try to empirically characterize the power and energy consumed by different servers and, in detail, by the CPU, the disk, and the network interface under different configurations. They also show how to estimate the energy consumed by an application as a function of some simple parameters - such as CPU load, the disk, and the network activity - through the measurement of the block size of the I/O operations. There is a large body of literature that considers the CPU as the responsible for the most power being consumed in a server, and that this power increases linearly with the load. Although the power consumed by CPU is significant, many researchers claim that the power consumed by other elements of the server, like disks and NICs (Network Interface Cards) are not negligible, and have to be taken into account. However, the authors in [7] believe that the CPU power consumption depends linearly from the load when the server has multicore and may operate at multiple frequencies. In [7] the empirical results show the power consumption pattern of CPU, disk and network but the core of the work is to estimate the energy consumption of applications. For this purpose, a formula is introduced:

\[ E_{\text{app}} = E_B + E_C + E_D + E_N \]

\(^\text{13}\) BS Seeker is a CPU intensive Bio-informatics application.
Where, $E_{app}$ indicates the energy consumed by an application and has as basic assumption that this energy is essentially the sum of the baseline energy $E_B$ (the baseline power times the duration of the execution), the energy consumed by the CPU $E_C$, the energy consumed by the disk $E_D$, and the energy consumed by the network interface $E_N$.

In detail, in [7] during the experiments, the authors take into account the I/O operations in order to characterize the power and energy consumption of disk; in each experimental case the CPU active cycles, the total power and time consumed in each of these I/O operations for each combination of block size and availability frequency are recorded.

In [11] the authors introduce energy-related metrics used today; an overview is provided:

1. **CPU:**
   - **Thermal Design Power (TDP):** it states the maximum amount of power which a CPU will dissipate at any time, making it an important metric during the design phase of, e.g., CPU coolers.
   - **Average CPU Power (ACP):** it uses workloads similar to standard industrial benchmarks to measure CPU power.
   - **Power Supply:** IT equipment runs on DC, and thus requires a PSU to convert the power coming from wall outlets.

2. **System Metrics:** different benchmarks can be used to evaluate computer systems. Different benchmarks usually use different energy efficiency metrics.
   - **JouleSort:** is an external sort benchmark which is able to evaluate the energy efficiency for a wide range of computer systems. To evaluate energy efficiency, external sort was chosen since it focuses on the I/O subsystem which has a significant impact on the overall power consumption. Furthermore, external sort stresses all key components of a system: memory, CPU, and I/O.
   - **SPECpower_ssj2008:** evaluates the energy efficiency of volume server class and multi-node class computers. The benchmark is implemented in Java, so it can be executed on almost all operating systems and platforms.

**Evaluating Energy consumption of workloads with Benchmark’ procedure**

“... The connection between performance and energy consumption is becoming necessary information for designers and operators as they grapple with power constraints in the data center. While industry and policy makers continue to strategize about a universal metric to holistically measure IT equipment efficiency, existing server benchmarks for various workloads could provide an interim proxy to assess the relative energy efficiency of general servers”[9].

Currently, many researches evaluate the energy consumption and performance of workloads using benchmark procedure. For example in [1] the authors studied several popular Linux file systems with different format options using a workload generator (FileBench) to emulate 4 server workloads: web server, database server, mail server and file server. The experiments campaign in [1] reveals a strong linearity between the power efficiency and performance of file system. The authors found significant variations in the amount of useful work that can be accomplished per unit of time or unit of energy. Several researchers use benchmarks similar SPEC to determine system power efficiency; the authors in [1] use metrics similar to the metrics into SPECpower_ssj (stresses a Java server with standardized workload at different load levels) but applied for file systems. The server was running the CentOS 5.3 Linux distribution; all the Filebench’ benchmark tests were executed on an external disk. The metric
used to measure the power efficiency is operations per joule (ops/joule) that is defined as the amount of work a file system can accomplish in 1 joule of energy.

Since, each workload targets a different application domain, the metric operations per second (ops/sec) is not comparable across workloads (e.g. a web server’ ops/sec are not the same of the DB server’).

<table>
<thead>
<tr>
<th>Workload</th>
<th>Average file size</th>
<th>Average directory depth</th>
<th>Number of files</th>
<th>I/O sizes</th>
<th>Number of threads</th>
<th>R/W Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web Server</td>
<td>32KB</td>
<td>3.3</td>
<td>20,000</td>
<td>1MB, 1MB</td>
<td>16KB, 100</td>
<td>10:1</td>
</tr>
<tr>
<td>File Server</td>
<td>256KB</td>
<td>3.6</td>
<td>50,000</td>
<td>1MB, 1MB</td>
<td>16KB, 100</td>
<td>1:2</td>
</tr>
<tr>
<td>Mail Server</td>
<td>16KB</td>
<td>0.8</td>
<td>50,000</td>
<td>1MB, 1MB</td>
<td>16KB, 100</td>
<td>1:1</td>
</tr>
<tr>
<td>DB Server</td>
<td>0.5GB</td>
<td>0.3</td>
<td>10</td>
<td>1MB, 1MB</td>
<td>16KB, 200+10</td>
<td>20:1</td>
</tr>
</tbody>
</table>

Table 15 Workload characteristics using Filebench (P. Sehgal et al.)

In conclusion, the benchmark' procedure is used by the authors in order to collect and analyze performance and power metrics through the evaluation of popular server workloads varying many parameters.

As said in the previous part of this section, it is important to understand the workloads of servers, both for provisioning server hardware as well as to exploit opportunities for energy savings and server consolidation. For this purpose, other works as well as the work [1], have exploited the I/O operations (e.g: IOPS/GB ratio, read/write ratios) in order to classify services workloads [10].

In [10] are summarized the most important summary metrics for the different workloads:

- **IOPS**: I/Os per second issued by the workload. IOPS is computed for each 1-second interval in the trace. In [10] the authors use the peak IOPS value to compare workloads, since servers are provisioned for this load.
- **R/W**: is the read/write ratio of the I/Os seen in the workload.
- **Seq**: is the fraction of I/Os that were considered sequential (e.g, the logical blocks read or written were contiguous to the immediately previous I/O).
- **GB**: is the size of the data set accessed by the workload, which is defined as the highest logical block number accessed expressed in units of GB.

### III.2.4. Workload-related metrics in HPC systems

In recent years, the HPC community has recognized the need to design energy-efficient HPC systems. The main focus has been on improving the energy efficiency of computation, resulting in an oversight on the energy efficiencies of the other aspects of the system (such as memory or disks) [4]. Therefore, to capture a more accurate picture of energy efficiency of a
HPC system a benchmark suite\(^{14}\) and associated methodology was used in several works in order to stress different computational components of a HPC system, such as the processor (or CPU component), memory and disk.

In the manuscript of Wilde et al. [2], the authors propose a metric called **Data Center Workload Power Efficiency (DWPE)** that is intended to be an energy efficiency metric for a specific workload running on a specific HPC system. In detail, DWPE will make the connection between workload energy efficiency of the HPC system and the DC infrastructure by combining the performance per watt (performance/watt) metric - which provides the measurement of the energy efficiency of the computer hardware used in a HPC system for a specific workload (eq. 1) – with PUE for the system in a DC.

\[
\text{Performance/W} = \frac{\text{average achieved performance}}{\text{average HPC it power used}}
\]

For a mathematical formalization of DWPE metric, it is necessary to introduce two additional metrics namely **Workload Power Efficiency (WPE)** and **system PUE (sPUE)**.

The first one is defined by:

\[
WPE = \frac{\text{average achieved performance}}{\text{average HPC system power used}}
\]

while, the second metric is provided by:

\[
sPUE = 1 + \text{Overhead}_{PDCL} + \sum_{k=1}^{n}(w_k + \frac{1}{\text{COP}_k})
\]

Where:

- PDCL stands for power distribution and conversion losses inside the DC (and the power \(P_{PDCL}\) provides a substantial contribution within PUE formula) and the Overhead\(_{PDCL} = P_{PDCL}/P_{IT}\) is the additional power needed by the DC to provide 1W of IT power.
- \(w_k\) represents the distribution for each heat removal technology k used in the hpc system and the sum of all \(w_k\) is 1 (equal to 100% heat removal).
- DC overhead incurred by cooling the system is represented by \(\frac{1}{\text{COP}_k}\) with COP=Coefficient of Performance, which is the power needed to remove 1W of heat via the heat removal technology k.

Note: \(PUE = 1 + \text{Overhead}_{PDCL} + \frac{P_{\text{Cooling}}}{Q_{IT}}\) with \(Q_{IT}\) is the power of IT converted into heat.

Hence, the DWPE formula can be written by the eq. 4:

\[
\text{Note: }PUE = 1 + \text{Overhead}_{PDCL} + \frac{P_{\text{Cooling}}}{Q_{IT}}
\]

\(^{14}\) Benchmark suite is a collection of benchmarks that provide better coverage and stress-testing of different components of the system.
and it can be used to calculate the HPC system efficiency for a specific workload in a given DC.

As defined in [3], the Energy-to-Solution (EtS) is another metric for measuring the energy efficiency of an HPC system for a specific workload. It shows the energy consumed by the HPC system for solving a specific problem using a specific application (eq. 5).

\[
EtS_{\text{workload}} = \text{runtime}_{\text{workload}} \times (\text{average HPC system power})
\]  

Further example of metric proposed to capture the work done by workload in a DC was provided by the use of a benchmark suit. In the work of Subramaniam and Feng [4], the authors proposed the The Green Index (TGI) for HPC.

In [4] the author also introduce the FLOPS/watt (eq. 6) metric in order to evaluate the energy consumed for a given amount of computational-work:

\[
\frac{\text{FLOPS}}{\text{watt}} = \frac{\text{Floating Point Operations Per Second}}{\text{Joules Per Second}} = \frac{\text{Floating Point Operations Per Joule}}{\text{Joules}}
\]  

Therefore, the metric should be chosen in such a way that is inversely proportional to energy consumed.

III.3. ENEA Experimental Campaign: step forward

Continuing the work illustrated in Deliverables D7.1 & D7.2, we have attempted to explore the possibility of defining “workload-related” metrics to measure the energy efficiency of a DC. In particular, in order to advance the line of research about the development of metrics that can authentically express a measure of the real “work” (computing) performed by a DC; we have explored for alternative solutions, and considered a methodology to develop a possible alternative through the use of benchmarks.

In our study we have run several selected benchmarks in order to seek a way to measure the useful work inside a DC, and relate this to the corresponding energy consumption. This procedure would of course greatly simplify the evaluation of useful work, albeit at the expense of accuracy, caused by the shift from a real case scenario to an “artificial” set-up.

In order to provide a guideline on benchmarks related-metrics procedure, we have planned and performed two separate experimental campaigns on the equipment available in ENEA' infrastructure\textsuperscript{15} and compared their outcomes.

\textsuperscript{15} The experiments were performed on a single node of ENEA's CRESCO4 facility (each compute node has two sockets, each with 8 core Intel Sandy Bridge processor-2.6GHz 64GB RAM).
In detail, this is the work that was carried out:

1. In a “real test” environment, two different web server platforms were set up, using Apache Tomcat and Nginx respectively. Identical configuration parameters were used. With Apache Jmeter a platform was created to generate intensive workloads and these were dispatched to the web servers. The corresponding energy consumptions were recorded.

2. In a “simulated” environment, with the Filebench tool, a platform was created to simulate the workloads and to measure their energy consumption. Thanks to Filebench workload generator we can simulate and stress the server and in this case a generic web-server was simulated with the same configuration tests of the previous experiment.

From energy perspective, in order to measure DC energy consumption, in addition to data retrieval from PDU, we adopted following software method

- **SMC-IPMI Tool**: It was developed by Sun Microsystems and measures energy consumption of nodes, processor, motherboard, RAM and devices.

In the following sections we will describe further developments that were carried out beyond the first ENEA experimental campaign. In a nutshell, we tried to acquire more detailed data on consumption, in particular for a webservice application. We unpacked consumption in detail and performed some new experiments, launching tests with and without the use of Dynamic Voltage and Frequency Scaling (DVFS) [29]. We also performed some load tests measuring the variations of energy consumption tuning the number of involved cores.

### III.3.1. New experimental campaign

Starting from the above-mentioned experiments, we carried out the measurements of energy consumption of individual components in order to understand, for each type of workload, the specific contribution of each component such as CPU, memory and other peripherals such as network card and others. In detail, we measured the power consumed by the CPU, the disk, the network interface etc. in different configurations, identifying the optimal operational levels, also considering the use of DVFS.

The work we carried out intends to:

1. Propose a technique in order to characterize the energy consumption of a server;
2. Provide “knowledge” on the individual power consumption of the components that contribute the most to the server's overall consumption, trying to provide a distribution of energy usage for typical server workload;
3. Provide a method to estimate the energy consumption of a typical data center application starting from the I/O operations parameter.
Before describing the experimental results it is useful to gather some facts on energy and power consumption of servers and how these change under different setups. There is a large amount of literature on the characterization of servers' energy and power consumption. Some references can be found in Appendix A.

Since in our new experimental works we decided to deeply investigate power consumption data, we also planned to measure consumption using (or not using) DVFS (dynamic voltage and frequency scaling). Another crucial aspect in this new phase of the experiment is to study the behavior of multi-core systems when exposed to intensive workloads.

The literature does not adequately consider phenomena like the flood of multicore servers and DVFS, which are key to achieve scalability and flexibility in the architecture of a server [13]. Although processor power consumption has usually been modelled in a linear trend, everything changed with the arrival of multicore processors able to work at multiple frequencies. Multicore processors have made several changes. First of all, cores in the same processor are able to share on-chip and on-die resources, increasing, hence, the synergies and reducing power requirements [14].

There are new parameters to be considered as variable voltages and frequencies that determine cpu speed and, consequently, power requirements. Due to this novel complication, being able to understand how servers consume power has become a must if we want to devise any technique or strategy that intends to reduce power or energy consumption.

DVFS can be organized with different governors or operating policies, which will condition the way frequency adapts to the load in the system. However, it is important to note that we cannot just reduce the frequency as much as we want, as it will affect the performance of the tasks being run in the machine. For this reason, usually, commercial implementations of DVFS have conservative policies whose main target is reducing working frequency, and therefore the consumption, of the machine when idle.

We used cpufrequtils tool to control the CPU frequency-scaling daemon. Frequency scaling allows us to set the CPU frequency on the fly or specify an automatic governor. Cpufrequency is available in the software repositories of most mainstream Linux distributions. Cpufrequency allow us to select available frequency steps for a particular processor and the available power governors.

Although processor power consumption has usually been modelled in a linear trend, everything changed with the arrival of multicore processors able to work at multiple frequencies. Multicore processors have made several changes. First of all, cores in the same processor are able to share on-chip and on-die resources, increasing, hence, the synergies and reducing power requirements [14].

There are new parameters to be considered as variable voltages and frequencies that determine cpu speed and, consequently, power requirements. Due to this novel complication, being able to understand how servers consume power has become a must if we want to devise any technique or strategy that intends to reduce power or energy consumption.

**Idle issue**

Servers are composed of various small parts where each one has its own share of power consumption. At the same time, the overall power utilization of each one of these parts is not constant; it depends by the stress we introduce in each of them. The power required by CPU, hard drives, memory, network and various devices depends on the quantity of processing we do, on the amount of memory that we use, on the amount of data we send or receive from the network and on the number of accesses we do to disk. The components listed above are usually assumed to be the major contributors to the power consumption of data center servers, and therefore we will neglect contributions and effects of other components.
A remarkable amount of power is consumed even when the server is idle. Hence, in order to collect significant data in terms of energy, the first step is to identify a threshold value for the idle state (Baseline of figure 8). Various experimental measures were repeated in order to precisely evaluate the idle state consumption ($E_{idle}$).

**Experimental set-up**

Our study analyzed the contribution to the total power consumption of different components of data center servers, namely, CPU, disks, and other peripherals (network card, etc) and their dependencies on certain parameters, like the frequency and number of active cores. We tried to isolate in particular the contribution of energy consumption due to:

1. CPU,
2. RAM memory
3. Disk I/O operations and other (e.g. network activity).

Just measuring server’s total energy consumption and a few activity indicators reported by the operating system.

- **IDLE** - As concerns the components energy characterization, we noticed that, besides the baseline (IDLE) consumption, the CPU has the largest impact among all components, and its energy consumption is not linear with the load. In any case, it is never possible to leave out the consumption during idle.

- **DISK I/O** - Usually the hard disk’s power consumption can be split into three main parts: idle, accessing and startup modes [15]. We analyzed in depth the input/output phase of the disk trying to count the number of disk reads and writes discovering that disk I/O operations are the second main cause of consumption, and their efficiency is affected by the I/O block size used by the application (stress test performed with Filebench, under suggestions of Vasily Tarasov[16]). Eventually, network activity plays a minor yet not insignificant role in the energy utilization, and the network impact scales almost linearly with the network transmission rate [1]. We discovered also that energy consumed by hard disks for reading and writing depends on the CPU frequency and the I/O block sizes as confirmed in [7]. Both reading and writing energy costs increase slightly with the CPU frequency. While the energy consumption due to reading is not affected by block size, the energy consumption due to writing increases with the block size. The reading efficiency (expressed in MB=J) is affected by the CPU frequency, while writing efficiency is a concave function of the block size since it boosts the throughput of writing until a saturation value is reached.

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16 Vasily Tarasov is a file system and storage researcher at IBM Almaden Research Lab.
Based on our observation, the CPU power utilization depends on the number of working cores, the CPU frequency, and the CPU load. Processors are divided into two categories: single-core and multi-core. Our experiments prove that the energy utilization with a single working core at constant frequency can be closely approximated by a linear function of the CPU load. However, as confirmed in [7], with a fixed CPU frequency, the energy consumption in a multicore architecture is a concave function of the CPU load and can be approximated by a low-order polynomial. Using the highest number of cores and the lowest frequency, at which the load can be served in general, minimizes the energy consumption for a fixed CPU load. However, the minimum achievable energy consumption is a piecewise concave function of the CPU load. We agree with what Fan et al. say in [18] where they quantize the power consumption with the general equation $P_{CPU} = P_{idle} + (P_{max} - P_{idle}) \times L /100$, where $P_{max}$ denote the maximum utilization of a processor (100% usage), $P_{idle}$ denote the phase of power consumption of no-activity of processor and $L$ the utilization of the processor (cpu usage). We derived $P_{max}$ by experimental data with benchmark load and well-known data in literature.

**NETWORK** - The energy consumption and the efficiency of the network interface card, both in transmission and reception, depend primarily on three parameters such as CPU frequency, the packet size, and the transmission rate (Figure 9). The efficiency of data transmission increases nearly linearly with the transmission rate. Although a linear relation between transmission rate and efficiency holds for data reception as well, small packet sizes yield higher efficiency in reception.

**OTHER** - All other components for example memory, fans, GPU, etc. can be accounted for the baseline energy consumption, which is subject to minor variations under different workload.

![Figure 10 Network card consumption](image)

We carried out all experiments on a server node consisting of dual 8-core Xeon Sandy Bridge E5-2670 processors. Each core of the E5-2670 processors has a 32 KB L1 instruction cache, a 32 KB L1 data cache, and a 256 KB unified L2 cache. All eight cores on a same die share a 20 MB L3 cache. The cores are DVFS capable and have 16 performance states, ranging from 1.2 GHz to 2.6 GHz in 0.1 GHz increments and, additionally, 2.601 GHz.

We started our measurements by profiling the CPU energy consumption, from where we obtained information about the baseline energy consumption of the servers and the energy consumption due to CPU load. Afterwards, we profiled the other components, namely, disk and other minor components such as RAM. It is worth to note that CPU and baseline measurements are of capital importance in order to evaluate the other components, because every time that we run a script to profile the behaviour of another component, some CPU cycles are needed in order to execute it as well as to use the component that has to perform the task. In general, as outlined by other authors [7] we provided the energy consumed by an application as sum of several terms:

$$E_{app} = E_C + E_R + E_N$$
\[ E_{\text{app}} : \text{energy consumed by an application} \]

\[ E_C : \text{energy consumed by the CPU} \]

\[ E_R : \text{energy consumed by the RAM} \]

\[ E_N : \text{energy consumed by the Network Card and others (motherboard, devices video, devices audio)} \]

Therefore, to understand the contribution of any component, we first needed to identify the contribution of the CPU (\( E_C \)), of the memory RAM (\( E_R \)), the baseline (idle) and total consumption (\( E_{\text{app}} \)). To explore the possible parameters, which determine the energy consumption of servers, and to obtain statistical consistency, we ran our experiments multiple times.

One of our main goals was to evaluate the impact of different workloads on power use. We selected four common server workloads: Web server, file server, mail server, and database server. The distinguishing workload features were: file size distributions, directory depths, read-write ratios, meta-data vs. data activity, and access patterns (i.e., sequential vs. random vs. append).

**Software packages & setup.** In order to monitor and store the consumption data we used Linux machines (with CentOS) with Intel Sandy Bridge processors from hardware side and FileBench (emulator of complex application) Jmeter, Phoronix and Faban benchmark tool from software side.

We used cpupowerutils (the evolution of cpufrequtils included as part of the tools/ directory in the upstream linux kernel source) an advanced support for CPU usage/power monitoring and other performance statistics. Cpupowerutils is a suite of tools designed to manage power states on appropriately enabled cpus. The cpupowerutils package takes all of the features from cpufrequtils [http://www.phoronix.com/scan.php?page=news_item&px=OTIwNg], but goes beyond just monitoring CPU frequency switching to better monitor deep sleep states, measure hidden Turbo Boost frequencies, and polling CPU/GPU power management support.

We performed the control of the consumption on the node starting with hosting Tomcat Web-Server using the SMCIPMI Tool by SuperMicro through the IPMI (Intelligent Platform Management Interface). In order to query the consumption values, we used the FreeIPMI tool.

Our measurements started characterizing the CPU power consumption, from which we obtain information about the baseline power consumption of the system. After CPU and baseline characterization, experiments for the other two components, namely, disk and network, were carried out. In a Linux system, CPU activity stats are constantly logged, so we can periodically record the core frequency and the number of active and passive CPU. We use active cycles per second to characterize CPU load, trying to compare it with number of I/O operations per second.

CPU load percentages cannot be compared when different frequencies are used. With specific tools, the CPU frequency at which the system works can be monitored and different frequencies to the cores can be assigned. However, to limit the number of possible combinations to characterize, we initially assigned the same frequency to all cores.

**Jmeter & Filebench** - In a “real test” environment (with Jmeter), two different web servers were set up (Figure 10), respectively Apache Tomcat and Nginx.

With Apache Jmeter a platform was created to generate intensive workloads and these were dispatched to the web servers. The corresponding energy consumptions were recorded in a “simulated” environment (created with the Filebench tool) in which a platform was created to simulate the same workloads.
In the case of Filebench, we have the total number of performed operations (IOPS). FileBench reports file system performance in operations per second, which the shell script collects. We ran all tests at least five times and computed the 95% confidence intervals for the mean operations per second.

In order to correctly evaluate energy consumption in the simulated environment, the idle consumption was singled out and subtracted with a procedure similar to the one carried out in the real environment.

Hence, we obtained the real energy consumed by workload thus:

\[ E_{workload} = E_{Tot} - E_{idle} - E_{init} \]

In the formula \( E_{init} \) represents the energy consumption by Filebench during the initialization phase.

Once we set a threshold for the idle state consumption (specifically 89W) we started the measurements of workloads and we calculated the actual time (expressed in seconds) in which...
the machine remains above this threshold. In figure 11 a comparative consumption in percentage observed with Filebench and Jmeter platform is shown.

![Comparative consumption in percentage with Jmeter and Filebench on Apache Tomcat with DVFS](image)

The CPU frequency was initially set at the lowest possible value for the system; a workload with fixed amount of load for one core was run and the corresponding power consumption and I/O operations were recorded. The whole process was repeated increasing by one the number of active cores by means of `CpuFreqUtility`. The whole was repeated until all the cores of the server were active. When more than one core was active, the load for all the active cores was the same. For the disks' side, we know that Filebench evaluates the power consumption of the hard drive using different scripts for reading and writing operations. For Apache Tomcat webserver we evaluated the OTHER portion sperimentally attributing 11% to mainboard, 6% to HardDisk, 4% to FAN, 20% to PCI slot. We ran the same load test with Apache Jmeter. We performed write (read) operations for a set of different I/O block sizes and for different data volumes to be written (read). In each case we recorded the I/O operations per second, the total power and time used in each one of these operations for several combination of block size and available frequency. The contribution of the hard drive to the total power utilization was identified, subtracting the contribution of the baseline, the CPU requirements and memory from the measured total power. Finally we investigated the contribution of the network to the power requirements of a server. We planned a set of experiments based specific scripts devised for his purpose.

### III.3.2. Main results

We collected a lot of consumption data trying to gain knowledge on the power consumption of the components that contribute the most to the server’s power consumption. The results are very significant and useful to understand in detail the origin and extent of server consumptions. Here below distributions of energy usage for typical server workload under different DVFS setting and a multicore architecture are provided.

<table>
<thead>
<tr>
<th></th>
<th>With DVFS</th>
<th>Without DVFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>50%</td>
<td>42%</td>
</tr>
<tr>
<td>RAM</td>
<td>21%</td>
<td>17%</td>
</tr>
<tr>
<td>OTHER</td>
<td>29%</td>
<td>41%</td>
</tr>
<tr>
<td>OTHER</td>
<td>29%</td>
<td>41%</td>
</tr>
</tbody>
</table>
Figure 13 Consumption in percentage in real test performed with Jmeter on 1) Webserver 2) Mailserver 3) DBserver 4) Fileserver with or without usage of DFVS

Filebench webserver

<table>
<thead>
<tr>
<th>Users - Pagesize in kb</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy in joule</td>
<td>no DVFS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>496</td>
<td>505,5</td>
<td>515</td>
<td>525</td>
<td>535</td>
</tr>
<tr>
<td>600</td>
<td>635</td>
<td>658</td>
<td>681</td>
<td>682,5</td>
<td>684</td>
</tr>
<tr>
<td>1000</td>
<td>659</td>
<td>684,5</td>
<td>710</td>
<td>716,5</td>
<td>723</td>
</tr>
<tr>
<td></td>
<td>Energy in joule</td>
<td>with DVFS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>502,94</td>
<td>512,57</td>
<td>522,21</td>
<td>532,35</td>
<td>542,49</td>
</tr>
<tr>
<td>600</td>
<td>633</td>
<td>656</td>
<td>674</td>
<td>675,50</td>
<td>683</td>
</tr>
<tr>
<td>1000</td>
<td>600,41</td>
<td>623,64</td>
<td>662,65</td>
<td>681,46</td>
<td>716,56</td>
</tr>
</tbody>
</table>

Jmeter on Apache Tomcat webserver

<table>
<thead>
<tr>
<th>Users</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>
The work presented is motivated by our disagreement with some of the models that have been proposed in the literature which state that power consumption of data center servers depends linearly on the load. Our belief is that more complex/complete models for the power consumed by a server are necessary. We found that, despite the large body of work in the field, there is a lack of empirical work studying server energy behaviour. Our work tries to propose a measurement-based characterization of the energy consumption of a server component with DVFS and multiple cores. Using different experimental settings, we evaluated the contribution to power consumption of the CPU, hard drive disk, network card and other components.

Table 18 Main difference of consumption between webserver workload with DVFS e without DVFS (Filebench (a), Jmeter (b))

<table>
<thead>
<tr>
<th>Pagesize in kb</th>
<th>Energy in joule no DVFS</th>
<th>Energy in joule with DVFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>390 415.22 420 435 498</td>
<td>395.46 421.03 425.88 441.09 504.97</td>
</tr>
<tr>
<td>600</td>
<td>427 436 452 511.5 535</td>
<td>423 429 451 509.5 529</td>
</tr>
<tr>
<td>1000</td>
<td>449 464.5 472 521.5 537</td>
<td>444.51 455.21 457.84 483.75 467.19</td>
</tr>
</tbody>
</table>

Table 19 IOPS with webserver simulated with Filebench

<table>
<thead>
<tr>
<th>Pagesize in kb</th>
<th>OP/S</th>
<th>Input/Output Operations Per Second</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>3241.96 3299.03 3353.94 3595.56 3828.14</td>
<td></td>
</tr>
<tr>
<td>600</td>
<td>3311.33 3289.13 3268.43 3499.35 3729.25</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>3952.12 3902.34 3856.14 4084.27 4308.29</td>
<td></td>
</tr>
</tbody>
</table>

A workload generator such as FileBench provides, at the end of the run, the total number of performed operations: Input/Output Operations Per Second (IOPS\(^{17}\)). Generally, in literature the IOPS are metrics used in some benchmarks and they are summarized as follows:

- Nominal Operating Power: a weighted average of the power consumption at different load operations, where the weight is the average number of watts observed in each of the profiles.

\(^{17}\) IOPS is a common performance measurement used in general to benchmark computer storage devices.
• Nominal Traffic (IOPS): similar to the metric above, the nominal traffic is a weighted average of the IOPS rates at different load operations, where the weight is the average number of watts observed in each of the profiles.

• Operating IOPS/Watts: assesses the efficiency with which the I/O traffic can be sustained. It is the ratio of the Nominal Traffic to the Nominal Operating Power.

• Annual Energy Use (kWh): estimates the average energy use computed across three selected environments, over the course of a year. The Annual Energy Use is given by: $0.365 \times 24 \times \text{Nominal Operating Power}$.

From a methodological point of view, we believe that I/O per second (IOPS) could be a new and more convenient metric for data center load.

It is possible obtain the parameter IOPS for different workloads generated by a workload generator tool. As each workload targets a different application domain, a metric based only on IOPS is hard to compare across workloads: i.e a web server's IOPS are not the same as, say, the DB server's one. Therefore, for our goal it was useful to consider the combination of the number of IOPS (available on all FileBench workloads) with the related energy consumption with the adoption of DVFS or excluding DVFS technology. Indeed, in our experimental campaign we selected a metric called Joule per operation (JOPS) in order to provide an "energy" weight for a single Filebench operation trying to link the energy consumption measured with the real test environments with the simulated with Filebench.

This metric could offer a possibility to investigate on the “cost” of a single atomic operation in terms of used energy, as well as could provide a fair comparison among workloads. However, we are far away to draw conclusion and in the perspective of workload related metrics more efforts should be devoted.
IV. APPENDIX A: SHORT REVIEW OF LITERATURE ON SERVERS POWER CONSUMPTION

There is a large amount of literature on the characterization of servers power consumption. However, the existing literature does not consider phenomena like the forced incursion of multicore servers, dynamic voltage and frequency scaling (DVFS) which are most important to achieve scalability and flexibility in the architecture of a server. With these new parameters to evaluate, more variables come into play in a server configuration. Learning how to deal with these new parameters and how they interact with other variables is important since this may lead to larger savings of energy [16]. It has been traditionally considered that the CPU is imputable for most of the power being consumed in a server, as illustrated in figure 15, and that this power increases linearly with the load. As we could see, the power consumed by the CPU is important, but the power incurred by other elements of the server, like memory, disks and network cards is not insignificant, and must be taken into account.

Moreover, we believe that the statement that CPU power consumption depends linearly from the load in a server is too “rough”, in particular when the server has multiple cores and may work at multiple frequencies. Sure enough, Figure 16 illustrates how processor energy efficiency (e.g., performance per watt) increases as server utilization increases for a typical workload in a typical representation.

Therefore, more complex and complete models for the power consumed by a server are necessary. We found that there is a lack of empirical work dealing with server’s energy behaviour.

The consumption of servers has been supposed as linear, e.g., by Mishra et al [19] or Beloglazov et al. [20] who assumed models in which energy consumption mainly depends linearly on CPU utilization.
Other works from Andrews et al. [21] or Irani et al. [22] proposed non-linear models, asserting that running processes at the lowest possible speed could save energy.

Between works not considering frequency we find articles proposing models where server components follow a linear behavior, such as in [15, 23].

In [24] Liu et al. proposed a simple linear model and estimate different hardware configurations and types of workloads by varying the number of available cores, the available memory, and considering also the contribution of other components such as disks.

In [23] Economou et al. proposed a non-intrusive method for modeling full-system energy consumption by stressing its components with different workloads. Their resulting model is also linear on the utilization of server components.

Going further with the studies and measurements, we also considered published works that consider frequency of the parameters analyzed. Brihi et al. [26] presented a deeply study of DVFS. They also presented interesting results about disk consumption illustrating a flat consumption in reading operations and variations in the writing ones that they attribute to the size of the files being written.

Even if it was not the main objective of their work, Raghavendra et al. [27] asserted that CPU power depends linearly on its utilization.

The authors in [28] modeled the energy consumption of data centers equipment (i.e., servers, storage, switches) for cloud computing based on existing energy consumption measurements or publicly available data sheets for each of the components (CPU, disk, network, switches). After all, Basmadjian et al. [14] showed an analysis of the components of a processor and its contribution to the energy consumption of the CPU.
V. REFERENCES


