GEYSER assessment and possible improvements

GEYSER
Green nEtworked data centres as energY proSumErs in smaRt city environments

Project FP7 – SMARTCITIES – 2013
Grant Agreement n°: 609211
D7.6/RWTH/WP7/V1.0

Start date of project: 1 November 2013
Duration: 36 months
D7.6 - Version 1.0 - 25/11/2016
Document. ref.: D7.6/RWTH/WP7/V1.0
**PROGRAMME NAME:** SMARTCITIES-2013  
**PROJECT NUMBER:** 609211  
**PROJECT TITLE:** GEYSER  
**COORDINATOR:** Engineering - Ingegneria Informatica Spa [ENG] (IT)  

<table>
<thead>
<tr>
<th>DOCUMENT NUMBER:</th>
<th>D7.6/RWTH WP7/V1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>WORK-PACKAGE:</td>
<td>WP7</td>
</tr>
<tr>
<td>DELIVERABLE TYPE:</td>
<td>Public</td>
</tr>
<tr>
<td>CONTRACTUAL DATE OF DELIVERY:</td>
<td>31/10/2016</td>
</tr>
<tr>
<td>ACTUAL DATE OF DELIVERY:</td>
<td>25/11/2016</td>
</tr>
<tr>
<td>TITLE OF DOCUMENT:</td>
<td>GEYSER assessment and possible improvements</td>
</tr>
<tr>
<td>AUTHOR(S):</td>
<td>Julie Chenadec, Vasiliki Georgiadou (GIT), Lisette Cupelli (RWTH)</td>
</tr>
<tr>
<td>APPROVAL OF THIS REPORT:</td>
<td>Paul Hughes (ABB), Tudor Cioara (TUC)</td>
</tr>
<tr>
<td>SUMMARY OF THIS REPORT:</td>
<td>This report concludes the validation and evaluation process by analysing the collected results and experience in a uniform, consolidated way. In doing so the report delivers evidence on the achieved performance along with guidelines towards the development of a market-ready solution.</td>
</tr>
</tbody>
</table>

**HISTORY:** See the Change History Table  
**KEYWORD LIST:** Evaluation; Assessment; Consolidated Results; Improvements; Improvements  
**AVAILABILITY:** Public
<table>
<thead>
<tr>
<th>Version</th>
<th>Date</th>
<th>Status</th>
<th>Author (Partner)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>17/05/2016</td>
<td>Draft</td>
<td>Vasiliki Georgiadou, Julie Chenadec (GIT)</td>
<td>Draft ToC</td>
</tr>
<tr>
<td>0.2</td>
<td>15/07/2016</td>
<td>Draft</td>
<td>Julie Chenadec (GIT)</td>
<td>Final ToC; SIAM analysis (Chapter 2)</td>
</tr>
<tr>
<td>0.3</td>
<td>20/09/2016</td>
<td>Draft</td>
<td>Julie Chenadec (GIT)</td>
<td>Updated Chapter 2</td>
</tr>
<tr>
<td></td>
<td>06/10/2016</td>
<td>Draft</td>
<td>Lisette Cupelli (RWTH)</td>
<td>Consolidated input from D7.4</td>
</tr>
<tr>
<td>0.4</td>
<td>14/10/2016</td>
<td>Draft</td>
<td>Joyce Dijkslag (Alticom)</td>
<td>Consolidated input from D7.5</td>
</tr>
<tr>
<td>0.5</td>
<td>25/10/2016</td>
<td>Draft</td>
<td>Marzia Mammina, Enrico Melodia (ENG); Julie Chenadec (GIT)</td>
<td>Consolidate input from D7.2; Update Chapters 2 &amp; 3</td>
</tr>
<tr>
<td>0.6</td>
<td>01/11/2016</td>
<td>Complete Draft</td>
<td>Vasiliki Georgiadou, Julie Chenadec (GIT), Lisette Cupelli (RWTH)</td>
<td>Updated Executive Summary, Introduction, Conclusions; Edited document; Released review draft</td>
</tr>
<tr>
<td>0.7</td>
<td>03/11/2016</td>
<td>Peer Reviewed</td>
<td>Tudor Ciocara (TUC)</td>
<td>Peer review</td>
</tr>
<tr>
<td>0.8</td>
<td>15/11/2016</td>
<td>Draft</td>
<td>Julie Chenadec (GIT), Marzia Mammina (ENG)</td>
<td>Consolidated input from D7.3</td>
</tr>
<tr>
<td>0.9</td>
<td>16/11/2016</td>
<td>Second Review Draft</td>
<td>Vasiliki Georgiadou (GIT)</td>
<td>Edited document; Released review draft</td>
</tr>
<tr>
<td>0.91</td>
<td>16/11/2016</td>
<td>Peer Reviewed</td>
<td>Tudor Ciocara (TUC)</td>
<td>Peer review (1)</td>
</tr>
<tr>
<td>0.92</td>
<td>17/11/2016</td>
<td>Peer Reviewed</td>
<td>Paul Hughes (ABB)</td>
<td>Peer review (2)</td>
</tr>
<tr>
<td>0.93</td>
<td>17/11/2016</td>
<td>Release candidate</td>
<td>Julie Chenadec, Vasiliki Georgiadou (GIT), Lisette Cupelli (RWTH)</td>
<td>Addressed review comments; Release candidate</td>
</tr>
<tr>
<td>0.99</td>
<td>23/11/2016</td>
<td>Quality Checked</td>
<td>Diego Arnone (ENG)</td>
<td>Quality check</td>
</tr>
<tr>
<td>1.0</td>
<td>25/11/2016</td>
<td>Final</td>
<td>Massimo Bertoncini (ENG)</td>
<td>Final approval</td>
</tr>
</tbody>
</table>
# Table of contents

List of Acronyms .......................................................................................................................... 8  
Executive Summary ......................................................................................................................... 10  
1. Introduction ............................................................................................................................... 11  
1.1. Purpose and Scope ................................................................................................................. 11  
1.2. Intended Audience .................................................................................................................. 11  
1.3. Relations to other activities ................................................................................................... 12  
1.4. Document overview ............................................................................................................. 12  
2. Description of the analysis process ............................................................................................ 13  
2.1. SIAM Analysis Overview ....................................................................................................... 14  
2.2. SIAM analysis as applied to the GEYSER pilot results ......................................................... 16  
2.2.1. Assessing an operational transfer of the GEYSER Solution ........................................... 16  
2.2.2. Creating a roadmap towards a market-ready solution ....................................................... 17  
2.2.3. Proof for the analysis ........................................................................................................ 17  
2.3. SIAM analysis mappings per test case .................................................................................. 21  
3. Evaluation of pilot results ......................................................................................................... 31  
3.1. Pilot classification scheme .................................................................................................... 31  
3.2. GEYSER Deployment, Monitoring, Control and Interoperability ......................................... 32  
3.2.1. Similarities and differences in the primary installation ...................................................... 32  
3.2.2. Overall achievements and lessons learned from the primary installation ....................... 34  
3.3. GEYSER Optimisation Solution ............................................................................................. 35  
3.3.1. Drivers and Constraints for the Evaluation ....................................................................... 35  
3.3.2. Assessment of the KPIs ...................................................................................................... 36  
3.3.3. Assessment and evaluation of pilot results ....................................................................... 37  
3.3.4. Relevance to operations ..................................................................................................... 40  
4. GEYSER Marketplace – GEM and GAM ............................................................................... 41  
4.1. Drivers and Constraints for the Evaluation .......................................................................... 41  
4.1.1. Assessment of the KPIs ....................................................................................................... 43  
4.1.2. Assessment and evaluation of pilot results ....................................................................... 43  
4.1.3. Suggestions for improvements towards a market-ready GEYSER solution ................... 46  
4.2. Pilot test bed improvements .................................................................................................... 46
4.1.1. RWTH test bed ................................................................. 46
4.1.2. Alticom test bed ............................................................. 47
4.1.3. PSM test bed ................................................................. 47
4.1.4. Terni test bed ............................................................... 47
4.2. Creating a roadmap towards a market-ready solution ........................................ 48
  4.2.1. Environmental .......................................................... 48
  4.2.2. Economical .............................................................. 49
  4.2.3. Technological ........................................................... 49
  4.2.4. Social ......................................................................... 50
5. Conclusions ........................................................................ 51
6. References ........................................................................... 52
List of Figures

FIGURE 1 - VISUAL OF THE SIAM ANALYSIS ............................................................................................................. 13
FIGURE 2 - DESCRIPTION OF THE ANALYSIS PROCESS ............................................................................................ 16
FIGURE 3 - ADDITIONAL BUSINESS VALUE BY IMPLEMENTING HIGH PRIORITY TEST CASES ........................................... 19
FIGURE 4 - LEGEND OF TEST CASES T01 AND T02 .................................................................................................. 21
FIGURE 5 - MAPPING OF TEST CASES T01 AND T02 ................................................................................................ 22
FIGURE 6 - LEGEND OF TEST CASES T04 & 05 .......................................................................................................... 23
FIGURE 7 - MAPPING OF TEST CASES T04 & T05 .................................................................................................... 24
FIGURE 8 - LEGEND OF TEST CASE T08 ................................................................................................................... 25
FIGURE 9 - MAPPING OF TEST CASE T08 ................................................................................................................. 26
FIGURE 10 - LEGEND OF TEST CASES T10 & T11 .................................................................................................... 27
FIGURE 11 - MAPPING OF TEST CASES T10 & T11 .................................................................................................. 28
FIGURE 12 - LEGEND OF TEST CASE T12 ................................................................................................................ 29
FIGURE 13 - MAPPING OF TEST CASE T12 ............................................................................................................... 30
List of Tables

**TABLE 1 - DEPENDENCIES AND LINKAGES** ................................................................................................................................................................. 12
**TABLE 2 - GEYSER FRAMEWORK APPLICATIONS MAPPING TO TESTS CASES** ........................................................................................................ 18
**TABLE 3 – TEST CASES AND MAIN INFLUENCED KPIs** ............................................................................................................................................... 20
**TABLE 4 - PILOT CLASSIFICATION SCHEME** ..................................................................................................................................................... 31
## List of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4D</td>
<td>4 Dimensions</td>
</tr>
<tr>
<td>APC</td>
<td>Adaptability Power Curve</td>
</tr>
<tr>
<td>APC_Ren</td>
<td>Adaptability Power Curve at Renewable Energies</td>
</tr>
<tr>
<td>API</td>
<td>Application Program Interface</td>
</tr>
<tr>
<td>B&amp;C</td>
<td>Benefits &amp; Concerns</td>
</tr>
<tr>
<td>CEF</td>
<td>Carbon Emission Factor</td>
</tr>
<tr>
<td>CSA</td>
<td>Cloud Software Adapter</td>
</tr>
<tr>
<td>DB</td>
<td>Database</td>
</tr>
<tr>
<td>DC</td>
<td>Data Centre</td>
</tr>
<tr>
<td>DCA</td>
<td>Data Centre Adapt</td>
</tr>
<tr>
<td>DCIE</td>
<td>Data Centre infrastructure Efficiency</td>
</tr>
<tr>
<td>DCIM</td>
<td>Data Centre Infrastructure Management</td>
</tr>
<tr>
<td>DSO</td>
<td>Distribution System Operator</td>
</tr>
<tr>
<td>DX</td>
<td>Direct Expansion</td>
</tr>
<tr>
<td>EE</td>
<td>Economic Expenses</td>
</tr>
<tr>
<td>ESCo</td>
<td>Energy Services Company</td>
</tr>
<tr>
<td>ESP</td>
<td>Energy Simulation Prototype</td>
</tr>
<tr>
<td>ESTE</td>
<td>Economic, Social, Technical, Environmental</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>GAM</td>
<td>GEYSER Ancillary services Marketplace</td>
</tr>
<tr>
<td>GEM</td>
<td>GEYSER Energy Marketplace</td>
</tr>
<tr>
<td>GDS</td>
<td>GEYSER Data Storage</td>
</tr>
<tr>
<td>HPC</td>
<td>High Performance Computing</td>
</tr>
</tbody>
</table>
ILM  IT Load Migration manager
IT   Information Technology
ICT  Information and Communication Technology
KPI  Key Performance Indicator
(k/M)Wh (kilo/mega) Watt-hour
MSD  Mercato del Servizio di Dispacciamento
OPC  Object Linking and Embedding for Process Control
PES  Primary Energy Savings
PESTEL-GS Political, Economic, Social, Technical, Environmental and Legal - Governance and Space
PSM  Pont Saint Martin
PUE  Power Usage Effectiveness
PV   Photovoltaic
REF  Renewable Energy Factor
RES  Renewable Energy Sources
RTCM Real Time Control Manager
SC   Smart City
SIAM Sustainability Impact Assessment Method
SLA  Service Level Agreement
SoSA Software Sustainability Assessment
SWOT Strengths, Weaknesses, Opportunities and Threats
TISC Thermo Information Simulation and Control
TSO  Transmission System Operator
UPS  Uninterruptible Power Supply
VM   Virtual Machine
WP   Work Package
Executive Summary

The present deliverable, entitled “GEYSER assessment and possible improvements”, is the final deliverable of Work Package (WP) 7 “Trials & Performance Assessment” and reports the results of the pilot trials and the lessons learned while testing the final GEYSER integrated framework. Deliverable D7.6 is composed from the collected results reported in the individual deliverables of each pilot; namely, D7.2 “GEYSER solution assessment in the Pont Saint Martin Italian testbed”, D7.3 “GEYSER solution assessment in the Terni Italian testbed”, D7.4 “GEYSER solution assessment in the German Testbed” and D7.5 “GEYSER solution assessment in the Dutch Testbed”.

The analysis in this deliverable goes beyond the pilots results and provides a SIAM – Value Assessment (Sustainability Impact Assessment Method) for enabling different stakeholders, such as DC managers but also Smart City/Smart District, energy providers, DSO and TSO, to leverage and use effectively the GEYSER solution.

The trial results of the RWTH pilot\(^1\) in Aachen, Germany, the Alticom pilot\(^2\) in Roermond, the Netherlands, the ENG Italian pilot in Pont Saint Martin (PSM)\(^3\), and the ASM Italian pilot in Terni\(^4\), are evaluated and compared with respect to the initial targets and methodology set in the deliverable D7.1 “Trials and evaluation process specifications” keeping a link between the overall achievements on one side and related KPIs (Key Performance Indicators), drivers and constraints for the evaluation of the GEYSER Solution which have an impact for future decision making on the other side. Moreover, the suggestions for system improvements and a roadmap towards a market-ready solution are elaborated and will be published to the relevant community.

\(^1\) This pilot site is mentioned as “RWTH pilot”, “German pilot” or “Aachen pilot” interchangeably throughout this document.

\(^2\) This pilot site is mentioned as “Alticom pilot”, “Dutch pilot” or “Roermond pilot” interchangeably throughout this document.

\(^3\) This pilot site is mentioned as “ENG pilot”, or “PSM pilot” interchangeably throughout this document.

\(^4\) This pilot site is mentioned as “ASM pilot” or “Terni pilot” interchangeably throughout this document.
1. Introduction

Environmental efficiency and energy flexibility are clear and distinct ways of paving the future of Green DC embedded in a Smart City environment. Improving existing DC represent an enormous opportunity for stakeholders to achieve higher performance on energy efficiency by re-thinking the way it’s being used but as well as defining new standards for new designed DC. The architectural advancements of the GEYSER solution will enable and help drive efficiency improvements of the DC markets. Nowadays, our high demand towards these huge facilities of data management must be shaped regarding the demand and the flexibility of a smart city or smart district. Due to their large energy consumption, we are aiming to bring innovation based on the maximisation of the efficiency and to look at every layer of the DC, what are the key operational drivers, and how this impacts energy use. Innovation is an integrated approach of the DCs’ world and it is shaping the way we are seeing them. From cooling to storage and flexibility, DCs are a key proactive player when it comes to achieving energy impact. Indeed, no two DCs are alike and this sector needs constant improvements.

This report concludes Work Package (WP) 7 of the GEYSER project and signifies the completion of its workings after a period of three (3) years. All four (4) pilot sites have tested the three major subsystems of the GEYSER framework and results can set a path for concrete applications in the marketplace:

- The GEYSER Monitoring and Control, which constitutes the “senses” of the GEYSER framework, collecting information on the business and energy status within the DC environment.
- The GEYSER Optimization Engine, which is the “brain” of the GEYSER framework, drawing the plans to schedule DC operations, individually or in cooperation with partner DCs, in order to meet high-level business or energy goals, locally or within the Smart City.
- The GEYSER Marketplace, which adds the “Smart City dimension” in the GEYSER ecosystem, allowing the Smart City energy stakeholders to set energy goals and/or provide or request energy flexibility.

The objective of the report is to conclude the pilot validation process by assessing the collected results and evaluating them in a consolidated way. Here we outline the potential dependencies and differences among the results in order to deliver proofs of the achieved performance and improvements for the development of a ready-to-market solution.

1.1. Purpose and Scope

Demonstrate the viability of the energy flexible DC concept by

a) Focusing on delivering practice based case studies outlining potential cost savings and carbon savings

b) Using well-established metrics and KPI’s and proactively promoting these metrics and KPI’s that are needed for the project.
1.2. Intended Audience

The target audience of this deliverable are potential adopters, in particular, DC managers and operators as well as decision makers, who could gain useful information on the experimental results of the GEYSER project and understand the benefits not only at the DC side, but also when contributing to Smart City level sustainability goals and the potential financial benefits through the participation in the GEYSER Marketplace.

Energy Retailers, Sellers, Traders, Aggregators and Distribution System Operators (DSOs), as well as Smart City Municipalities could benefit from participation on the GEYSER Marketplace in order to promote green energy usage and contributing to the Smart Grid stability.

1.3. Relations to other activities

Although this deliverable can be considered as a standalone document, it takes into account work conducted in past deliverables and will, accordingly, affect future ones such as the D8.4. Table 1 shows such dependencies and linkages.

<table>
<thead>
<tr>
<th>ID</th>
<th>Title</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>D7.1</td>
<td>Trials and evaluation process specifications</td>
<td>Dependency; pilot and test set up</td>
</tr>
<tr>
<td>D7.2</td>
<td>GEYSER solution assessment in the Pont Saint Martin Italian testbed</td>
<td>Dependency; results of trials in PSM DC.</td>
</tr>
<tr>
<td>D7.3</td>
<td>GEYSER solution assessment in the Terni Italian testbed</td>
<td>Dependency; results of trials in ASM Terni DC.</td>
</tr>
<tr>
<td>D7.4</td>
<td>GEYSER solution assessment in the German Testbed</td>
<td>Dependency; results of trials in Aachen DC.</td>
</tr>
<tr>
<td>D7.5</td>
<td>GEYSER solution assessment in the Dutch Testbed</td>
<td>Dependency; results of trials in Roermond Altimoc DC.</td>
</tr>
<tr>
<td>D8.4</td>
<td>Impact creation achievements and exploitation planning</td>
<td>Handover in relation to exploitation plans and business cases; roadmap for a market ready solution.</td>
</tr>
</tbody>
</table>

1.4. Document overview

The remainder of this report is organized as follows:

- Chapter 2 presents the analysis process;
- Chapter 3 evaluates and assesses the pilot test-beds;
- Chapter 4 discusses suggestions for a market-ready solution;
- Chapter 5 draws conclusions and summarizes the report.
2. Description of the analysis process

The 12 test cases defined in D7.1 *Trials and evaluation process specifications* have achieved ambitious results in the four (4) pilot sites, in Italy, Germany and The Netherlands. The objective of the analysis process is to link a test case to a service bundle that have been developed in D8.4 *Impact creation achievements and exploitation planning* to maximise the project impact and its business value for the future of green networked DCs. The rich and diverse set of functionalities performed in the four DCs are targeting different components of the GEYSER solution.

This analysis paved the way for enabling and offering the different stakeholders’ significant and innovative improvements to implement multiple financial benefits through an increased energy efficiency. The stakeholders are not only DC Managers and Operators but also Smart City Managers, Energy Providers, DSOs and TSOs.

In this chapter, we will focus on describing the analysis taken for assessing the results.
The analysis called SIAM – Value Assessment (Sustainability Impact Assessment Method) performed in the following chapters has been made possible through a collaboration between GIT and Vrij University (VU) from Amsterdam. This work enables the smart integration between strategies outlined through the assessed KPIs and categorization of drivers, followed by the mapping of the case environment though a 4D model where we tend to highlight potential impact and support trade-offs analysis for future decision making. The result will lie in the assessment of the actual impact and the validation for adopting those measures.

We will explore why the SIAM analysis fits with the results obtained thanks to the pilots and how we envision the future of green and interconnected DCs. In direct collaboration with the results, we are specifying a way to successfully achieve the transfer of any scenarios to a different organisation and by enabling this transfer, we are creating the opportunity of a roadmap for any organisation who are not ready to start exploring the innovative flexibility that make possible the GEYSER solution.

2.1. SIAM Analysis Overview

SIAM analysis is an intuitive and comprehensive approach based on the integration of known models which results in the value’s assessment of the GEYSER’s test cases scenarios. The model is set to be flexible to assess different kinds of practices, in this DC related scenarios. Uncovering and assessing strategy and sustainable drivers is important for any organisation that want to apply a practice. The detailed SIAM analysis will be executed to understand the value of the results and presented in a consolidated way.

The key question for the GEYSER project to perform a SIAM analysis is: How does the GEYSER Solution impact the KPI results?

For this analysis, we have combined three models, namely the PESTEL-GS analysis, 4D Model Mapping and SoSA Mapping, where each of them bring a key value for the overall assessment of the practice. The aim of the analysis carried out is to assess and quantify the results and to measure the success factor of the practice’s implementation. It is a model of potential sustainability impact visualizations linked to strategy/practice elements (e.g. strategy goals, indicators, stakeholders).

✓ **Determine the context:** Analysis of the scenarios and their relevant policies to set a « contextualisation » framework

PESTEL GS is an acronym based on a well-known marketing method. It is a tool traditionally used by marketers to analyse and monitor the (external) marketing environment factors that have an impact on an organisation. The result of the analysis is often used to identify threats and weaknesses as input for a SWOT analysis. The acronym is based on the abbreviation of Political, Economic, Social, Technical, Environmental and Legal.

The PESTEL GS analysis has been developed to identify the stakeholders, their underlying drivers and the potential benefits and concerns for a project initiative or (envisioned) solution ‘practice’. The GS has been added to identify those aspects in relation to the topic of Governance and Space (the physical environment).

The first objective is to collect data that set main drivers and concerns and enable a classification addressing or hindering the sustainability concerns of the practice. The second objective of a PESTEL-GS analysis is to help
contextualize the case study. The PESTEL-GS analysis does contain eight different layers/categories that have specific goals for an overarching strategic analysis. Moreover, the PESTEL-GS analysis involves measurable metrics, the identification of best-fit KPI’s and targets related to the drivers. This data collection will be map as key input for the next steps of the analysis.

✓ 4D Case Analysis: Mapping and representation in four sustainability dimensions and their related dependencies

During this step, a mapping will be performed for each of the test cases from a 4D perspective accompanied by quantified or qualified formulations of impacts. KPI’s and other indicators identified during PESTEL-GS will be used here. Having set the classification of drivers and their related target, there are now two steps to conduct the analysis.

The first one is to identify the stakeholders and map their concerns and benefits into the 4D model to highlight potential dependencies which will lead to some expected impact assessment, namely the SoSA mapping. The second step after the case mapping is to set the expected impact of the practice. The objective here is to calculate the impact through the identified KPI’s and identify which drivers and concerns are impacted. If needed at this stage, we can also identify the remaining concerns that need to be addressed. We have now all the relevant information for the 4D model analysis’s output.

The result of this approach to the impact assessment exercise will ensure that the impact is assessed from all four dimensions of sustainability landscape of the projects solution design and their relations to the stakeholders.

✓ Value Assessment: Enabling trade-offs analysis

We have settled a foundation to build a relevant assessment of the results – thanks to the mapping of activities of both potential Benefits and Concerns (B&C) and results – we are now able to assess the actual impact of the selected measure. This step validates the outcomes from the previous steps and the impact of all scenarios combining the KPI results from the GEYSER pilots’ test cases.

The value assessment brings together the results from the previous exercise in impact assessment and connects them to the initially identified stakeholders, drivers and resulting quantified/qualified indicators. This mapping exercise creates a visual impact landscape that is designed to support trade-off analysis and decision-making indicating where and to what extent the positive or negative impacts (in relation to the stakeholders’ and their drivers) occur within the solution environment. It also provides insights to the market value of the designed solution.

✓ Measure the results: Evaluation to facilitate future decision making and implementation

The final step is to measure the results and compare the actual impact versus the expected impact. This step is important to uncover final concerns that you can think of and have a relevant visualization of the implementation you want to carry out.

To conclude, the SIAM analysis is a great analysis to provide solid (qualitative and quantitative) arguments to determine if the implementation was successful and where it was successful.
practice and the different assessment made allow any organisation to look at the specific configuration they want / prefer to implement. That is why it is a flexible model to uncover sustainable strategy and related impact.

2.2. SIAM analysis as applied to the GEYSER pilot results

The reduction of related environmental impact has been a driving force and an objective for the last decades for stakeholders and GEYSER fits in this vision of finding new ways to lower negative consequences and increase positive impact on business models. Environmental awareness is at the heart of the pilots where we are combining new tools to achieve positive results for the DC and the related stakeholders (i.e.: SC managers, TSOs, DSOs, DC Managers, etc.) and where we are enabling new functionalities that stem from smart actions.

The reason why we have chosen to conduct this analysis for all the test scenarios is dual:

1. Assess an operational transfer of the GEYSER Solution to any stakeholders that wishes to implement it
2. Create a roadmap for a market-ready solution

2.2.1. Assessing an operational transfer of the GEYSER Solution

The most relevant theory of transferring good practices relies on three different contents: technical, informational and managerial. In our case, we are going to focus on the technical transfer – also named as the Technology Transfer – which is relying on the transfer of skills, knowledge, technology applications and exchange of ideas and solutions, in others words, good practices that can be implemented by the participants of the project.

The test scenarios are very specific – one field of action, one outcome – so it is very difficult to formulate the “mechanism” it relies on. To understand how the test scenarios works, we need to know the conditions and the context where they have emerged.

PESTEL and the more extensive SIAM analysis is a strategic tool to assess and evaluate the environment of a company, and in our case, to analyse and structure the context of the good practice, which can affect the activities and performance. This combined model allows to make sure no aspects are forgotten that could be relevant from policy-making to implementation and to describe the context in which the good practice emerges. The objective is to evaluate the influence of the test scenarios’ drivers in order to understand what will be the impact of the pilot’s result.
Transferring a practice is a complicated task because one needs to understand why it works and the reason why this particular practice has been chosen and implemented. By making effective use of the SIAM analysis, one ensures that the work done is aligned positively with the powerful forces of change that are affecting the surrounding working environment. Using the SIAM analysis will allow an efficient implementation because all the drivers have been understood, as well as, their related dependencies and different impacts that come up with practice. By taking advantage of the inevitable change, one is much more likely to be successful.

Resulting from the pilots, we have now in our possession multiple innovative results for enabling a roadmap towards a GEYSER market ready solution. The designed model and analysis carried out looked at many different drivers, categorized into different aspects. This diversity of research carried out for the test-scenarios is paving the way for further development and innovation for the DC.

2.2.2. Creating a roadmap towards a market-ready solution

The objective of the roadmap is to gather different kinds of input – such as drivers, stakeholders and their related dependencies – that will exploit the overall energy flexibility of the GEYSER Suite. The need to create a roadmap is based on the will to include other DCs that may be not ready to start implementing visionary and advanced solutions. The motive to move forward with a roadmap make sense for every transfer we can enable.

The reason why we have integrated the PESTEL-GS & SIAM analysis to our pilot analysis is to showcase the proof of this transfer and enable any of the organisation to implement it. What we are aiming to achieve is to build upon the results of the pilots to enable different stakeholders – DC Managers & Operators, DSOs, ESCos & traders (i.e.: energy market managers), Smart City (such as city planners, Smart City energy managers) – that wishes to implement the GEYSER modules to be able to match as much as possible their requirements with the modules they want to implement.

We have gathered inputs into the same logic as the 4 Dimension mapping in order to keep a consistency among our stories. This is important to be able to separate and highlight drivers in different categories because each category may not apply to all stakeholders. For example, the Smart City manager will be more inclined to see drivers for success in the Social part because he/she needs to understand the vision before selling to a marketplace. A DC manager will rather look into Economical benefits, and thus cost savings becomes a key figure for DC management.

An extensive version of the roadmap will be delivered in the D8.4, consolidating results from Chapter 4 and the timeline for implementation.

2.2.3. Proof for the analysis

During the analysis, we have created various tables to make the outcomes more tangible during the technological transfer adoption of the different modules, based on the test cases conducted in the four test-beds.

Table 2 represents the key modules to implement based on the priority of the test case. This mapping of the different test cases is important to consider because they represent the step to take while any stakeholders wishes to apply the GEYSER solution to their company/organisation.
This means that the priority will define the scenario to implement at first and the ones that need to put more time effort on if the stakeholder wishes to reach the results he expects to achieve. Failing to take this into consideration might result in an incorrect way of implementing the test scenario.

**Table 2 - GEYSER framework applications mapping to tests cases**

<table>
<thead>
<tr>
<th>GEYSER Framework Applications</th>
<th>Test Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GEYSER Deployment, Monitor and Control</strong></td>
<td>Mappings were developed</td>
</tr>
<tr>
<td>GEYSER Optimisation Solution</td>
<td>T01 – IT workload consolidation</td>
</tr>
<tr>
<td></td>
<td>T02 – Managing delay tolerant workload</td>
</tr>
<tr>
<td></td>
<td>T04 – Dynamic adjustment of the cooling intensity</td>
</tr>
<tr>
<td></td>
<td>T08 – Local generation devices</td>
</tr>
<tr>
<td></td>
<td>T05 – Pre-cooling a server room for more flexibility</td>
</tr>
<tr>
<td></td>
<td>T06 – Dynamic use of the thermal storage</td>
</tr>
<tr>
<td></td>
<td>T07 – Electrical Storage devices</td>
</tr>
<tr>
<td></td>
<td>T09 – Plan periodic maintenance of back-up generators</td>
</tr>
<tr>
<td>GEYSER Marketplace Interaction</td>
<td>T10 – Buy/sell energy manually from the GEYSER energy marketplace</td>
</tr>
<tr>
<td></td>
<td>T11 – Buy/sell energy automatically from the GEYSER energy marketplace</td>
</tr>
<tr>
<td></td>
<td>T12 – Accept an offer to provide ancillary services on GAM</td>
</tr>
</tbody>
</table>

While performing the mapping exercise part of the SIAM analysis, we realized that by assessing the high priority test cases, all the modules that are part of the GEYSER Framework Applications are represented (see the table above). Although the GEYSER Marketplace test cases were not referenced as High priority, it is important to map these test cases as the GEYSER Marketplace is one of the key components of the overall architecture and for a Smart City environment perspective.

It is worth to mention that by mapping key test scenarios, we are assessing all the KPIs initially considered. The choice of not covering certain scenarios was motivated by the fact that the KPIs previously identified for 12 test scenarios are basically equivalent in these tests. The focus made to work on particular tests and not the others are still interesting for these last ones as we still assessing key concepts for the market-ready solution.

Moreover, focusing more time and effort on high priority tests will result in better results, we need to understand why these test scenarios have settled a higher priority than the others. The five different categories of results, namely: **Verification of data collection robustness**, **IT Workload Consolidation**, **Managing Delay Tolerant Workload**, **Dynamic adjustment of the cooling intensity** and **Local generation devices**, will indeed impact the other test scenarios’ execution. The relation between test scenarios will depend on the priority of test scenarios.
The paragraphs below are primarily research about each high priority test case in order to give a glimpse about the results we expected from each pilot. The main driver in common for all test scenarios is the economical perspective that gives the DC either additional revenues or savings. When Energy Efficiency is one of the key drivers of the DC, Economic Savings is the ultimate goal.

“Verification of data collection robustness” is the most important to start with; on one hand, the use of DCIM encourages the efficient use of energy, supports virtualisation and consolidation, and improves data centre availability; On the other hand, data collection and communication can be also done leveraging on existing BMS (Building Management Systems) through the DCIM adapter. The result of both approaches enables the GEYSER solution to exploit flexibility and better manage the DC’s resources, it also allows the balance of computing and power capacity against IT load even if when it fluctuates quickly; holding computing costs down in a dynamic environment.

“IT Workload Consolidation” and “Managing Delay Tolerant Workload” can be performed independently or at the same time. Demonstrating a workload consolidation and managing the workload at peak times comes with multiple benefits for the DC Operator and Manager. The DC must be performant and therefore, using a software-defined platform to easily adapt and sustained performance as well as reliability is vital. Also, the higher utilization, the increased efficiency and economy of scale it leverages.

The cooling optimization in which “Dynamic adjustment of the cooling intensity” is assessed, is an aspect that can really make a difference. Although a high-power deployment will result in more cooling, there is significant room for improvement when it comes energy prices and/or availability of renewable energy sources by switching on and off power management settings to ensure the most efficient use of DCs.
The Smart City concept could not be complete without a feed-in grid flexibility to support the needs and wants of the stakeholders. This is the ultimate integration that a Smart City needs to operate for being able provide a stability in the consumption and obtain costs savings. Thus, the “Local generation devices” look at how by using the GEYSER Energy Simulation Prototype (ESP) for the actuation of UPS (Uninterruptible Power Supply) batteries and diesel generator we can test the flexibility actions.

The approach of targeting the high priority test scenarios is based on the risks and concerns that DCs can be confronted with if these high priority actions are not implemented at the beginning. This risk-based [1] approach will give organisations more flexibility to do what is necessary to implement and to enable proactive processes to help the organisations succeed. By identifying and anticipating gaps that can be overcome by implementing those actions, organisations will control and understand better their frameworks, increase the efficiency of the DC and be smarter in decision-making.

Following the identification of priority actions to implement, we now need to analyse which KPIs are most influenced in order to better analyse and map the results. The importance of the KPIs lies in the fact that KPIs are able to determine the behaviour of the analysed DCs and to measure its performance:

- Measure energy/power consumptions: PUE
- Measure use of RES (Renewable Energy Sources), energy reused and flexibility of DCs to minimize their energy consumptions and environmental footprint: APC, APC_Ren, DCA, REF, PES, CO2 Savings, EE

Based on our study of the KPIs per test scenarios, we can now have a better picture of the ones used within the whole GEYSER solution and tested in real live environment. Table 3 presents the consolidated results.

Table 3 –Test cases and main influenced KPIs

<table>
<thead>
<tr>
<th>Test cases</th>
<th>No KPI</th>
<th>Economic Expenses</th>
<th>DCA</th>
<th>Grid Interaction Factor</th>
<th>PES</th>
<th>CO2 Savings</th>
<th>REF</th>
<th>APC</th>
<th>APC_Ren</th>
</tr>
</thead>
<tbody>
<tr>
<td>T00</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T01</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T02</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T03</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T04</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T05</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T06</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T07</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T08</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T09</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.3. SIAM analysis mappings per test case

For this section, we have added the different mappings that have been performed based on the input collected from the partners and the previous analysis.

We have chosen to consolidate different kinds of input such as:

- The *Technical Capabilities* of the test case, namely what is needed to configure and make it run
- The *Drivers* that are related to the Stakeholder(s)
- The *KPIs* needed to evaluate the result of the practice

By consolidating these sets of information, we can provide an overall landscape of the test cases, from the beginning of the deployment until the impact with the results.

---

Legend: Test Cases
‘IT Workload Consolidation & Managing Delay Tolerant Workload’

**Actors**

- Stakeholder
- Driver
- KPI
- Technical Capability

**Case Specific abbreviations**

- **Technical Capabilities:**
  - OD: Openstack Deployment
  - CS: Compatible Servers
  - SM: Scheduler Module
  - GSCL: Generate Synthetic Customer Load
  - ACN: API Node and a controller node

- **KPIs:**
  - PUE: Power Usage Effectiveness
  - EE: Economic Expenses
  - TPC: Total DC Power Consumption
  - ITL: IT Load

- **Drivers:**
  - ITF: Identify IT Load Flexibility
  - RPC: Reduce Power Consumption
  - IU: Increase % Utilization
  - PPC: Reduce Peak Power Consumption
  - LET: Use Lowest Available Electricity Tariff

- **Stakeholder**
  - DC: Data Center Manager

---

*Figure 4 - Legend of test cases T01 and T02*
Case purpose: The innovative GEYSER Framework is here executed to assess the technological proof-of-concept workload flexibility for the DC environment.

Conclusion from SIAM mapping exercise:

- The mapping of the test cases related to the IT Workload and its related flexibility action has been successfully performed. The map visualises the correlation between different sets of data.
- It also shows us that test cases have been covering all dimension of the 4D except for the Social dimension.
- We can prove that dependencies do exist between the environmental and technological dimension.
- Results show us up to 15% of reduction in the Economical Expenses by consolidating and shifting IT load according to the energy price signal.
Legend: Test Case
‘Dynamic adjustment of the cooling intensity’

Figure 6 - Legend of test cases T04 & 05
Case purpose: The GEYSER Framework is performed to reduce energy consumption with innovative cooling flexibility actions.

Conclusion from SIAM mapping exercise:

- The mapping of the test case related to the Dynamic Cooling and its related flexibility action has been successfully performed and we can see correlation between different set of data.
- For low IT load conditions per rack (emulated using heaters), a reduction in the Economic Expenses of up to 35% resulted from a dynamic adjustment of the cooling intensity.
- With the flexibility created by allowing the temperature to rise between the ASHRAE guidelines (i.e. reducing cooling intensity), primary energy savings of up to 40% and CO₂ savings of 17% could be accomplished.
- As in the previous SIAM mapping exercise conclusion, all 4 Dimensions have been covered except for the Social because no social KPI nor Driver has been formulated for Stakeholders.
- PUE is not connected to any Drivers as it was emulated for these test scenarios (T04 and T05). Usually the PUE in the Dutch Pilot is around 1.2 since free cooling is used under normal operating conditions.
Legend: Test Case
‘Local Generation Devices’

Legend

- Stakeholder
- Driver
- KPI
- Technical Capability
- Complementing relation between Technical Capabilities & KPIs
- Complementing relation between KPIs & Drivers
- Complementing relation between Drivers & Stakeholders
- Complementing relation between drivers
- Conflicting relation between actors

Case Specific abbreviations

Technical Capabilities
- MBD: Modelling of the back-up diesel generator
- GED: GEYSER ESP Deployment
- IUD: Installation of UPS Batteries and Diesel Generator
- IGA: Integration of GDS API

Drivers
- PSG: Price Scheme met for the grid
- GS: Grid Stability
- IR: Increase amount of Revenue
- ROC: Reduce Operation Costs
- FEG: Feed Energy in the Grid
- RPC: Reduce Power Consumption
- IREP: Increase local Renewable Energy Production usage
- FCI: Fuel Costs Integration

KPIs
- PUE: Power Usage Effectiveness
- EE: Economic Expenses
- TPC: Total DC Power Consumption
- ITL: IT Load

Stakeholder
- DC: Data Center Manager
- DSO: Distribution System Operator

Figure 8 - Legend of test case T08
**Case purpose**: The GEYSER Framework is assessed to actuate energy sources to partially power the DC when the energy price is high.

**Conclusion from SIAM mapping exercise**:

- The mapping of the test case related to the operation of local generation devices to obtain cost savings has been successfully performed leading to 3.40% reduction on the Economic Expenses.
- We can see correlation between different set of data such as the economical DSO & DC’s point of view, triggered by technical dependencies related to the reduced power consumption and grid stability.
- Like in the others mappings, the Social dimension is not covered as the GEYSER Solution is focused on cost savings, technological development and environmental integration.
Legend: Test Case ‘Buy/sell energy manually/automatically from the GEYSER energy marketplace’

Legend
- Stakeholder
- Driver
- KPI
- Technical Capability
- Day-ahead Market
- Intra-day Market

Complementing relation between Technical Capabilities & KPIs
Complementing relation between KPIs & Drivers
Complementing relation between Drivers & Stakeholders
Complementing relation between drivers
Conflicting relation between actors

Case Specific abbreviations

Technical Capabilities
- GDC: GEM Deployed and Configured
- DSS: Day-ahead session scheduled
- ISS: Intra-Day session scheduled
- RM: Registration of Market participants
- GDS: Geyser Marketplace Data Storage Deployment
- RP: (Registration) of 31 Reference prices

Drivers
- LPE: Lower price for energy
- VCRC: (Reduced) value chain length and related costs
- ILD: Incentives offered by local DSO
- PA: Prosuming Activities (Buy and Sell Energy)
- LEM: Local Energy Market
- GEP: Green Energy Production
- FG: Feed In the Grid

KPIs
- CO2: Carbon dioxide Savings (equivalent)
- CS: Cost savings
- VE: Volume of Energy
- MPT: Market Participant Transaction

Stakeholder
- DC: Data Center Manager
- DSO: Distribution System Operator

Figure 10 - Legend of test cases T10 & T11
**Case purpose:** Validate economic and environmental benefits resulting from GEYSER Energy Marketplace

**Conclusion from SIAM mapping exercise:**

- The mapping of the test case has been successfully performed.
- We can see correlation between different set of data such as economic benefits when taking part of a local energy market.
- Undoubtedly, environmental impact can be achieved through the green energy production and savings of CO₂ emissions.
- The Intra-day and Day-ahead markets are distinct markets but we chose to have one mapping due to their similarities compared to the differences.
- All part of 4 Dimensions are covered to have a full visualization of the landscape of the practice.
Figure 12 - Legend of test case T12
Case purpose: Validate economic benefits resulting from GEYSER Ancillary Services Marketplace

Conclusion from SIAM mapping exercise:

- The mapping of the test case related to the GEYSER Ancillary Services Marketplace to obtain economic benefits has been successfully performed.
- We can see correlation between different set of data such as mainly economic benefits when part of a local energy market and being able to offer flexibility.
- Certainly, cost-effectiveness of procuring ancillary services help the DSO and the DC to share resources.
- All part of 4 Dimensions are covered to have a full visualization of the landscape of the practice.
3. Evaluation of pilot results

Among the considerable achieved energy efficiency, we will proceed in this chapter to the analysis of the results obtained via the pilot sites which are detailed in the previous deliverables, respectively D7.2, D7.3, D7.4 and D7.5. The focus will be on each result, obtained for the three subsystems of the GEYSER framework.

3.1. Pilot classification scheme

<table>
<thead>
<tr>
<th>Types of DCs / Flexibility Components</th>
<th>Alticom DC (Colocation DC)</th>
<th>PSM (Colocation DC)</th>
<th>Terni DC (Small Enterprise DC)</th>
<th>RWTH DC (HPC DC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SW 23</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>WW10</td>
</tr>
<tr>
<td>Average PUE</td>
<td>2.1³</td>
<td>1.52</td>
<td>1.9</td>
<td>1.7</td>
</tr>
<tr>
<td>Related Electrical Power</td>
<td>60 KVA</td>
<td>2 MW</td>
<td>40 Kw</td>
<td>200 kW</td>
</tr>
<tr>
<td>GEYSER Deployment, Monitoring, Control, Interoperability</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>IT Workload (Optimization Action)</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Cooling (Optimization Action)</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel Generator (Optimization Action)</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Marketplace (Smart City Integration)</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GEYSER assessment and possible improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP7 – SMARTCITIES – 2013</td>
</tr>
</tbody>
</table>

In this section, we have classified the test beds with various criteria that are of importance when considering the roadmap to enable a market ready solution but also to match the previous SIAM analysis that have been performed on certain test scenarios.

Within the GEYSER Experiments, we have demonstrated different concepts – optimization of resources, flexibility of consumption, production activity, etc. – in the 4 test beds DCs. We have successfully tested all the scenarios in all types of DC that are present in the market (except big cloud providers)– see the type in the table above. This classification is very important to consider the level of flexibility they can achieve as part of their business requirements.

---

³ 2.1 was emulated and that under normal conditions Alticom has a PUE of less than 1.2. The PUE of 1.12 is under free air cooling conditions and the PUE of 2.1 is under dx-cooling conditions.
Moreover, based on the service bundles as identified in D8.4, we also classify the DCs regarding the services they can offer.

In other words, we have mapped the business criteria to achieve a successful implementation of the GEYSER Solution and based on the results we get and the SIAM analysis previously performed, we can obtain specific conclusion for the roadmap. With this categorization, we are able to capture input for enabling different frameworks configurations to be implemented during the roadmap.

3.2. GEYSER Deployment, Monitoring, Control and Interoperability

The first part of this section is based on the evaluation and assessment of the twelve test cases prior to the delivery of their results. The GEYSER Monitoring and Control, which constitutes the “senses” of the GEYSER framework, collecting information on the business and energy status within the DC environment. It is worth mentioning that the primarily tasks such as installing the solution, configuring it and making it run and work with the underline configuration, are the most important steps in the pilots’ sites.

We noticed that similar deployments in the components are equivalent due to the similarities of the test cases and additional effort are put for integrating more modules in the high priority test cases.

An interesting parameter to mention is the fact that no two DC’s are alike. Every DC has made its own independent choices on physical layout, configuration, installations and monitoring and control. This implies that GEYSER should be a highly flexible solution that can be adapted to the specific needs of a DC.

3.2.1. Similarities and differences in the primary installation

3.2.1.1. RWTH test-bed

For the primary installation of the GEYSER solution 4 VMs were allocated and 11 physical servers were operated for the test cases regarding the testing of the IT Workload capabilities in the GEYSER Suite, namely the T01 and T02. Additionally, some installations were necessary to collect data of IT usage and energy consumption. These data were collected at rack, server and VMs level and therefore, the OpenStack deployment is a key installation for the successful integration.

In T01 and T02, the first task for enabling the workload consolidation mechanism requires to generate synthetic customer load to utilize the respective VMs and consolidate and/or shift the delay-tolerant workload, the power consumption of the servers has been upscaled moderately for observable results. The OpenStack deployment in T02 needed significant work as it has to be integrated with the IT and non-IT monitoring system and with the GEYSER Multi-criteria Optimizer components, thus, a scheduler module has been developed and has a direct impact for the OpenStack integration.

Generally speaking, deploying the IT Optimisation components on a testbed is a non-trivial process, primarily due to the well-known complexity of OpenStack; however working remotely made things more complex (more coordination, delays, etc.) although the team was pleasantly surprised by the few problems encountered.
T03 complete functionalities – Cloud Software Adapter (CSA), Service Level Agreement (SLA) renegotiation Manager and IT Load Migration Manager (ILM) – It was not possible to test in real life as more focused has been put at performing IT workload consolidation (T01) managing delay-tolerant workload (T02).

The simulation experiments corresponding to T07: Electrical Storage Devices and T08: Local Generation Devices were performed in using the GEYSER Energy Simulation Prototype (ESP) for the actuation of UPS batteries and diesel generator to test the flexibility actions. ESP had a dual objective to provide the non-IT equipment monitoring data and estimate the DC energy consumption, generation and storage.

For the completeness of T07, the use of UPS batteries are triggered by the GEYSER Multi-criteria Optimizer and the remaining energy on batteries and energy consumption on the cooling equipment is simulated with the ESP. The GEYSER Data Storage (GDS) has been modelled to receive automatic data posting from the ESP through the ESP adapter using the GDS Application Program Interface (API).

T08 is similar to the T07 by leveraging the ESP capabilities to generate non-IT monitoring data, providing simulated data for the power output of the diesel generator and the energy consumption on the cooling equipment and exchange of commands (strings), floating point numbers and integers between the ESP and the GDS API is possible through a TISC\(^6\) server, which enabled coupling of clients running in different environments, in this case for the integration of the ESP Dymola (Modelica [2]) and Matlab [3] for the ESP adapter. The preliminary tasks before performing T08 were the modelling of the back-up diesel generator and the inclusion fuel costs in the calculations.

3.2.1.2. Alticom test-bed

Alticom has free air cooling capacity equipment – ventilators, (de)humidifiers, Direct Expansion (DX) machines (emergency back-up cooling) and condensers – already in place, therefore, this high flexibility system makes it more possible to test the degree of flexibility for optimisation actions. T04 and T05 experiments have been conducted in a way that they will trial both test scenarios. Installation of additional servers, sensors, (remote control) heaters have been executed by the partners of the project. For T04, data from the GEYSER platform were recorded on the various VM’s and processed by the Optimizer at various IT load conditions which were generated utilising commissioning test heaters. Free cooling was disabled for the test and the DX units were up and running, with the RTCM (Real Time Control Manager) trigger these units to shut down via temperature set point modification whenever the GEYSER Optimiser with required reduction of cooling demand.

3.2.1.3. PSM test bed

To validate T06 scenario and its related optimisation strategies, the use of a “virtual” thermal storage has been considered meaning that the thermal energy is stored in the water mass in the cooling pipes – the inertia of the cooling pipes – available on site. OPC Server is installed to collect data from Sensors and Meters measurements and the DC inertia is evaluated from the water temperature values at output and input of the Hydraulic manifold. Specific OPC IDs have been listed to the data monitored but not stored in the GEYSER Data Storage.

\(^6\) TISC is a co-simulation environment that makes it possible to connect calculation models across more than one simulator and couple these into one system and simulation
In PSM is it not possible to feed the grid with the energy produced by the backup generators, therefore, the results obtained operating a simulation of T09 test scenario for the DC to operate in islanding mode.

3.2.1.4. Terni test bed

The ASM pilot has been designated to host the GEYSER Energy and Ancillary Services Marketplaces. Since based on the metrics defined to assess the ASM pilot there is no added value in distinguishing between the manual and the automatic placement of bids/offers in the GEYSER Marketplace, it has been decided to merge the test scenarios T10 and T11 in a unique test scenario T10 “Buy/sell energy manually/automatically from the GEYSER energy marketplace”.

3.2.2. Overall achievements and lessons learned from the primary installation

3.2.2.1. RWTH test-bed

The achievements of the IT workload optimization actions in T01 & T02 were successfully obtained due to the OpenStack configuration and integration with IT and non-IT monitoring subsystem.

T03, as described before, was reduced in emphasis due to time constraints, although the basic mechanisms to realize this were demonstrated.

The deployment of the ESP adapter for T07 and T08 has been connected to the GDS API to provide non-IT simulated data such as the power consumption on the cooling equipment; the remaining energy on batteries, which is the case for T07, and the diesel generator power output which is used in T08.

3.2.2.2. Alticom test-bed

Installation of GEYSER, including the various software components on local servers, temperature and electricity sensors should preferably be performed by one provider. The provider that would be responsible for all aspects of the installation. In research project, this aspect proved to be difficult since different partners were responsible for installing different components GEYSER framework.

The specific location and design of Alticom allows the space to heat up slower if the volume is larger than the capacity of the IT-load, and will heat up faster if servers are fully loaded and emitting a lot of heat. The remote-controlled heaters available at Alticom provide incremental increasing steps of 2kW from 0 to 12kW. This enables heating up the space at 4 and 12kW for recreating the low/high indoor heating intensity which represents low and high IT load conditions, respectively.

3.2.2.3. PSM test bed

It is assumed that the Optimiser in T06 should suggest to the DC Manager a plan proposing as optimisation action the dynamic usage of the thermal storage. The Optimiser deployment in PSM is not able to suggest such optimisation action since additional monitoring data, currently not available, would be needed.

T09 is based on simulated data and economic consideration, therefore, no physical operation is performed.
3.2.2.4. Terni test bed

Having the photovoltaic plant on site provides data for the availability of green energy on site generated and surplus of energy. Using this information, interactions with the GEYSER marketplace as well as maximizing the use of locally renewable energy can be analysed.

3.3. GEYSER Optimisation Solution

The GEYSER Optimization Engine, which is the “brain” of the GEYSER framework, draws the plans to schedule DC operations, in order to meet high-level business or energy goals, locally or within the Smart City.

This section presents a consolidated version of the test cases evaluating the GEYSER optimisation solution such as the IT load consolidation and managing delay-tolerant IT workload, adjustment of electrical cooling devices, and so on.

3.3.1. Drivers and Constraints for the Evaluation

3.3.1.1. RWTH test-bed

The consolidation of the IT workload (T01) at certain time slots successfully reduced the DC power consumption when the servers without active load have been powered down. The increment on the power consumption of the server where the IT workload is consolidated is smaller than the collective power consumptions of the underutilized servers prior the IT consolidation. In this manner, the DC power consumption is decreased when the energy price is high and a reduction in the Economic Expenses is achieved; specifically, an average reduction on the IT power consumption of 43.95 kW and 66.43 kW in the total DC power consumption and a reduction of up to 15% in Economic Expenses was achieved.

Shifting delay-tolerant workload in T02 is one of the flexibility actions that comes in handy when the goal is to adapt and reduce the DC consumption according to the energy price. In the tests performed the amount of delay-tolerant workload is around 10% of the total IT workload. There is no reduction on the DC energy consumption with this technique, instead, cost savings can be obtained by shifting the load to period when the energy price is low. Hence, the actual cost savings are strictly dependent on the DC’s energy tariff. For the case considered a reduction between 2.53% and 9.60% in the Economic Expenses was achieved.

T07 and T08 main focuses respectively where to charge or discharge the energy stored in batteries to modify the DC energy consumption profile and operate local generation devices to obtain cost savings in both situations. Unfortunately, none of the Pilots involved in the project agreed to operate the UPS batteries (T07) or operating the diesel generator (T08) for testing purposes; therefore, these tests were performed via simulation using the GEYSER ESP integrated with the GEYSER Multi-criteria Optimizer through the GDS. The difficulties on training the prediction module of the Optimizer due to limited time after deployment (i.e. lack of historical data sets for calibration) caused estimation errors on the battery capacity which led in some occasions to overcharging. Before going on real-life, the prediction module should be accurate enough and additional protection of the equipment must be ensured. Nevertheless, in the current deployment the Optimizer, a reduction on the Economic Expenses of up to 5% was achieved for T07, and 3.39% for T08.
3.3.1.2. Alticom test-bed

Installing software components, like GEYSER components, on local servers at the Roermond Data Centre (RDC) is one thing, making them work together faultlessly another. These types of issues occurred and were dealt with during the project. The final GEYSER prototype has been successfully installed, included the GEYSER Multi-criteria, as it is a key module of the GEYSER Solution and it is needed in order to be able to compute KPIs. The successful integration of DCIM, RTMM, Optimiser and DC Console have enabled collection, analysis and dissemination of live performance data and KPIs from physical field devices through to cloud based applications and validated the GEYSER concept. More careful consideration is required, however, before closing the loop in the opposite direction, and removing final authorization of strategies and actions from the system into the physical layer in order to maintain the required standards of reliability, quality and safety.

3.3.1.3. PSM test bed

During T06, measurements from sensors and meters are collected by an OPC Server and extracted by a custom script for the successive analysis. Thus, all OPC IDs assigned to each measurement must be identified and linked to the data monitored for the test purpose. It is assumed that the GEYSER Multi-criteria Optimiser can suggest to the DC Manager a plan proposing as optimisation action the dynamic usage of the thermal storage. The Optimiser in PSM is not able to suggest such optimisation action since more monitoring data, currently not available, would be needed. To evaluate the DC inertia, the water temperature values at output and input of the Hydraulic manifold are monitored. As the two refrigerating units GF1 and GF2 have the same characteristics, we are assuming that GF2 has the same behaviour of GF1 (the only one whose energy consumption is monitored by a dedicated sensor) during the test run.

Provided that the use of generators set is mandatory once per month (for maintenance), the aim of the T09 is to evaluate when supplying the DC through the generators considering the electricity prices variation is more convenient. In all simulations, the energy cost for the DC in case of grid supply and in case of islanding operation has been computed.

3.3.2. Assessment of the KPIs

3.3.2.1. RWTH test-bed

Various KPIs identified for the test scenarios in the Aachen DC have been computed by the Optimizer such as Economic Expenses and Carbon Savings, and PUE and APC_Ren were computed by the KPI engine; however, the KPIs calculated by the Optimizer were based on predictions of the DC consumption (before execution of the Optimizer actions); therefore they might be misleading when the prediction module is not properly calibrated. DCA was not computed due to its complexity as highlighted by the partners involved in the KPIs’ calculation.

3.3.2.2. Alticom test-bed

For every test scenario, influenced KPI’s were stated. For the evaluation of the test results, the methodologies from the Cluster Activity Task 3 – related to the KPIs and Metrics – were used to successfully compute EE, DCA, PES and CO2 savings and quantify the test impacts.
3.3.2.3. PSM test bed

For T06, four out of the five KPIs previously identified have been successfully computed. This has given the analysis good results.

Regarding the T09, as the aim of the test is to evaluate when supplying the DC through the generators considering when the electricity prices variation is more convenient, we have computed KPIs mainly based on economic considerations.

3.3.3. Assessment and evaluation of pilot results

3.3.3.1. RWTH test bed

T01 proved successful in reducing the DC power consumption. The actual set-up of this experiment has been already scaled up for observable results. The completeness of T02 resulted in reducing the DC operational costs. These types of flexibility action is suitable for HPC DCs such as the Aachen pilot but also for big warehouse DCs, as well as Enterprise DCs. However, for T01, its execution in Collocation DCs is much more complex and there is more at stake since this test involves the management of client’s workload, which itself is constraint by SLAs. Delays due to latency in the communication might negatively impact service provisioning, which is essentially the business case of Collocation DCs. For T02, the applicability issues for Collocation DCs are related to (negatively) impacting service provisioning.

Naturally, not all of the tests were successful first time – working with OpenStack technologies (which have had limited real world validation) inevitably requires modifications to system configurations, modifications to configuration files, sometimes modifications to the underlying code and some persistence.

Additionally, for T02 the results are highly dependent on the percentage of delay-tolerant workload that the DC has during one day and on the variability of the IT workload profile.

On both T01 and T02, to really test the behavior of the system, the use of more physical servers would be required. This would have meant access to more IT resources which is not trivial to realize. The tests demonstrated that the functionality worked and showed modest results for a small scenario, but there remain questions over how it scales.

- For T01, the reduction on the DC power consumption of more than 65 kW was achieved when the consolidation was first trigger by the Optimizer and then operated through the identified inactive load servers. This resulted in a reduction between 12-15% of the total DC energy consumption economic expenses which is the enabling impact for implementing this test case. CO₂ savings of up to 13% were obtained.

- T02 has reached a reduction on the Economic Expenses of up to 10% was achieved by shifting delay-tolerant workload meaning that the test case demonstrated that the DC peak power consumption can execute a delay-tolerant workload when the energy price is low, while the PUE remains the same value. No CO₂ savings were obtained.
T07 was successful demonstrating the reduction in the DC operational costs by simulating the GEYSER ESP with the Optimizer through the GDS. This type of flexibility action is suitable for all types of DCs, especially for those with a distributed and/or redundant UPS architecture such as Enterprise DCs, HPC DCs, Collocation DCs and Big warehouse DCs, where the back-up supply operation is not impaired because at least one UPS is always set for this purpose. For small DCs, that usually have one UPS, this flexibility action is not suitable. The cost of maintenance and operation of the UPS should be included as part of the market exploration of the GEYSER solution.

- In T07 the expected result requiring that the total DC consumption adjusted the charge and discharge of batteries accordingly to the energy price lead to a reduction on the Economic Expenses between 0.27% and 5%, based on the assumed energy tariff conditions. However, the CO₂ emissions were slightly increased, leading to -0.44% in the CO2 savings metric in the worst case.

The simulation of T08 was successful in testing the functionality of operating the Diesel Generator on request to reduce the DC operational costs. This type of flexibility action is suitable for all types of DCs, especially for those with a redundant back-up supply such as Enterprise DCs, HPC DCs, Collocation DCs and Big warehouse DCs, so that at least one diesel is always set for this emergency supply purposes. For small DCs, this flexibility action is not suitable. The cost of fuel needed for the operation of a diesel generator is high, usually more expensive than using energy from the grid; hence, it should be included as part of the market exploration of the GEYSER solution.

- A reduction on the Economic Expenses of 3.39% was achieved in T08 under simulated conditions where the operation of the diesel generator is instructed by the Optimizer when the price is high to operate and fed-in the grid energy. The use of fuel to power diesel generator impacts negatively the CO₂ emissions, since in Germany the CO₂ emissions per kWh is relatively low (due to high penetration of RES), this is reflected by CO2 savings metric (-35%).

3.3.3.2. Alticom test bed

Executing T04 and T05 took considerable more time than expected because in Research Project is more likely to learn, develop and test at the same time.

Test capabilities at the RDC were restricted to the existing configuration of the cooling installations. This was not initially foreseen. An example: it was not possible to use a wide range of set point changes (18-27°C), due to restrictions in the software configuration of the free air cooling units. Nevertheless, Alticom is convinced that the set points used in the test form a good basis for the project evaluation.

The test results showed that – provided the proper conditions are met – pre-/post cooling a server room is possible and – at the same time –energy consumption can be shifted in time. Letting the temperature rise, and cooling the temperature back to its original level is a feasible solution to increase flexibility. The compact nature of the module, and consequent low thermal inertia limited the potential for optimisation actions under high heating intensity conditions because the time the chillers remain off is very short and they then struggle to maintain temperature level or even return to original conditions. Further development of the concept on sites with greater available thermal capacity would provide for greater to scope to modify consumption patterns.
The reduction in energy consumption that can be achieved are significant over a short period (35% of total energy consumed for a duration of 30 minutes). This test result could only be generated with a low IT load, compared to the available air volume. With a high IT load, no significant energy reduction was realized. The volume of air simply heated up to quickly to effect the operating cycle of the DX compressors.

- T04 results concluded that by increasing the temperature set point of the cooling installation it is possible to reduce the associated energy consumption. Until the higher set point is reached, energy reduction is significantly reduced (cooling installation is almost completely switched off). For tests with a low IT load, a 2 degree raise in set point (26-28) showed that the cooling installation consumed significantly less energy for 20-30 min. For tests with a high IT load, the test results were less concluding. Due to the high IT load, the existing volume of air only provided a reduction for a minimal period. The preliminary conclusion is that energy reduction can only be achieved if the time it takes for the air to reach the higher set point is more than 10 min. (switch on/off time for cooling).

- T05 successfully demonstrated that more flexibility can be added by pre- and post-cooling the server room. If the energy for the additional cooling can be provided by RES, a reduction per set point change, is approximatively 3,25 kWh, with a 2 degrees’ change. In the design criteria for ICT equipment allowable temperatures are between 18 and 27 degrees Celsius. 18 degrees could be used as lowest allowable temperature and 27 degrees as highest allowable temperature. The temperature range of 9 degrees is the flexibility range that can be used. The mechanism as explained in T05 will only help to reduce (brown) energy consumption, if renewable energy can be used to bring the set point back to its original state, although it would have potential economic benefit by load shifting away from peak tariff periods.

- To sum up the KPIs results for the 2 test cases – since the experiments have been conducted in a way that they will trail both test scenarios, an economic saving up to 35% could be established by optimization of the cooling system. The DC adaptability is relatively high with a value of less than 0.8, which means that the DC adapts slightly to changes. The PES could save primary energy up to 40%, as for the CO2 savings, 16.7% reduction in CO2 emissions. The PUE of 2.1, being an average colocation DC, was emulated.

3.3.3.3. PSM test bed

The PSM pilot does not own a physical thermal storage to perform the T06 but it is possible to use as “virtual” thermal storage the thermal inertia of the cooling pipes. The tests runs have proved the good thermal inertia of the PSM pilot DC. The use of the thermal energy stored in the cooling pipes has allowed a saving, even if not high, in terms of primary energy and CO2. Moreover, the DC thermal inertia implies a DC flexibility that can be used to support the grid when critical conditions occur.

- The expected results in T06 successfully computed various KPIs. First the PUE is equal to 1.5 and in the Data Center infrastructure Efficiency (DCiE) it's equal to a percentage of 75 – which means an efficient DC. The DCA is less than 1 so we can conclude that the DC adapts slightly to changes. With less than 10% in savings of primary energy, the PES is a reliable KPI to assess. Both the CO2 savings and the EE are less than 5%. EE has the same value of CO2 Savings because we consider the energy cost as constant during the test for both the baseline profile and the current profile. In case of variable energy costs, the GEYSER Solution allows to have a
higher savings, when the energy cost is high. This implies a higher spread between the baseline cost and the current energy cost with a consequent higher EE value.

For the test T09, the PSM pilot DC is not able to feed the grid with the energy produced by the backup generators because those generators are used only to supply the DC in emergencies and, for this reason, the PSM DC has not ever been equipped with electrical component needed to feed the grid. Thus, the test case has been updated considering the opportunity for the DC to operate in islanding mode. The Italian National Single Price has been assumed as reference price for this test.

Four simulations have been performed:

- the first is performed in the 4 hours of day when the energy prices are lowest;
- the second is performed in 2 hours of day when the energy prices are lowest (hour 4:00 and 5:00);
- the third is performed in the 4 hours of day when the energy prices are highest;
- the forth is performed in 2 hours of day when the energy prices are highest (hour 20:00 and 21:00).

As a result for T09, the spread between the costs of energy from the generator sets and from the grid during the hours with the lowest energy cost is higher than the same spread during the hours with the highest energy cost. Thus, considering that the generator sets maintenance is mandatory (once a month) and exploiting the GEYSER Solution, which can suggest operating in islanding mode during the hours with high energy prices (based on energy price forecasts), the DC has the opportunity to spend less than it normally would spend.

The negative value of EES metric with less than -1,10 is based the cost of the electricity produced by the generator which is set higher than the cost of electricity bought from the grid.

For the PES reaching -0.40, we have obtained the same value of primary energy savings both for the cases of two hours and four hours of generators set operation. Indeed, the generators set consumption of “primary energy” is higher than the primary energy that would be consumed in case of Italian grid supply. This is due to the value of “total primary energy weighting factor”, which is 2.3 for the Italian electrical power system and to lower efficiency of PSM DC generators set in electricity production.

Regarding CO₂ Saving metric of about 4.5%, a lower carbon emission factor (CEF) have been used for electricity produced by the generator than the Italian electrical power system CEF. For all test runs, we got the same value of CO₂ Savings. Since the energy used during the test is locally produced, there are no grid losses and this implies a saving in term of CO₂ emissions.

3.3.4. Relevance to operations

3.3.4.1. RWTH test bed

The test equipment for T01 and T02 with 11 servers was operated independently. The DC normal activities were carried on without interruption. While deploying and testing this system, there was an issue with a server failure. Some of the servers provided for this work are older servers and it was necessary to replace one of them – RWTH replaced the server in a timely fashion.
The priority between tests T01, T02 and T03 have been modified as the project evolved, partners considered that T01 and T02, respectively a mechanism to deliver energy savings when performing IT workload consolidation and shifting delay tolerant workload, would have more important focus than T03 previously identified as high priority. Being able to react and adapt the need for the GEYSER Solution will benefit in its results. T03 has still successfully implemented the basic mechanisms in the Aachen pilot site.

For the tests T07 and T08, since the DC and its connection to the grid were simulated, there were no effects on the real operation of the DC. In fact, due to the reason mentioned and its flexibility, the ESP is a great tool for evaluating the optimization plans before real-life execution. If real equipment is to be operated, protections must be ensured. T08 would have been much more interesting if PV generation would have been available on site, to assess the carbon savings of a “Green” prosumer.

### 3.3.4.2. Alticom test bed

In general, testing a software solution like GEYSER in an operational DC environment, creates a lot of barriers and constraints. Other DC management systems have to be (temporarily) disabled or circumcised and precautions have to be made to (negatively) influence service provisioning. The GEYSER project was no exception. Initial assessments on timing for test preparations, have proven to be optimistic and the preparation of tests T04 and T05 took longer than expected. This was also due to logistical constraints and delays, like delays caused by longer than expected ordering time for specific equipment, such as sensors and servers.

It also showed during the execution of tests that it was not possible to switch on DX units in linear steps (0-25%-50%-75%-100%). These units could only be switched on and off. Together with its suppliers of DX units, Alticom is currently reviewing internally if these steps can be made part of the future configuration of DX units to enhance future flexibility.

### 3.3.4.3. PSM test bed

In order to avoid any interruption in the normal DC operation during T06, the test has been run only twice and to evaluate better the thermal capacity, more test runs should be done trying to understand how long the refrigerating units can be maintained switched off to understand better the thermal inertia and the cost effectiveness.

The T09 has been only simulated, as the PSM pilot is an operational DC and the normal activities cannot interrupted. The maintenance of the backup generators is a mandatory activity. Whiteout changing the DC equipment, the PES and the CO₂ Saving metric values cannot change; the EES value, instead, changes based on the electricity prices.

### 3.4. GEYSER Marketplace – GEM and GAM

Test scenarios including the GEYSER Marketplace add the “Smart City dimension” in the GEYSER ecosystem, allowing the energy stakeholders to set energy goals and/or provide or request energy flexibility.

For these test scenarios, besides the test ID and the purpose of the test and the initial conditions, a detailed description of the test providing a step by step procedure and timing is provided. The expected outcomes, influenced KPIs and the pilot site applicable to the test scenario are also specified. It should be noted that the considered KPIs
along with their measurement methodology are those identified and suggested within the Smart City Collaboration Cluster and in particular within the relevant reports released by the cluster, of which the GEYSER consortium is an active member.

3.4.1. Drivers and Constraints for the Evaluation

For each day of the experiment for T10 and T11, the sessions for the Day-Ahead and Intra-Day variant of the GEM have been scheduled.

Twelve actors have been registered into the GEYSER Marketplace Data Storage as market participant; among them, one actor has been registered as Market Operator, one as DSO, while the rest ten have been registered as Market Participants. All market participants are granted access in both Day-Ahead and Intra-Day variants of GEM. Without loss of generality, each Market Participant is assumed to place only one type of market action (bid or offer) per market session: 5 participants shall post bids and 5 participants shall post offers. Each market participant represents either a DC Manager manually participating in GEM or a DC automatically participating in GEM as a result of selected optimization plans, including actions of buying or selling energy in GEM. As both ways of GEM participation are equally handled by GEM and do not affect the marketplace operation, no differentiation is made between them in the pilot tests.

Furthermore, 31 reference prices have been registered into the GEYSER Marketplace Data Storage for both the Day-Ahead and Intra-Day marketplace: those reference prices are medium values of the daily energy price from the Italian market (the values are Euro/MWh), which ranges from 33 to 44€/MWh.

Based on the GEM operation, at the end of each session the market is cleared and at the end of the day the invoices are generated for each market participant.

For each day of the experiment for T12, the sessions have been scheduled for the GAM.

Twelve actors have been registered into the GEYSER Marketplace Data Storage; among them, one actor has been registered as Market Operator, one as DSO, while the rest ten have been registered as Market Participants for all the service variants (Regulation, Reserve, and Reactive Power Control). Each Market Participant shall only place sell market actions. Each Market Participant represents a DC Manager who wants to trade manually in GAM. In addition, one actor has been registered as Market Operator and one as DSO. The DSO acts as a central counterparty in GAM: it is the unique buyer with respect to the offers placed in the market by the service providers.

No variant similar to GAM are currently present in the Italian market; thus a unique reference value of 350 Euro/MWh has been assumed for the Reserve Capacity Ancillary Service with a validity time of one year; this value is the medium daily value related to June for the Italian MSD (Mercato del Servizio di Dispacciamento). The same unique reference value has been assumed for the Regulation Ancillary Service with a validity time of one year. Based on considerations on Reactive Power selling price to end user in Medium Voltage, which includes also grid management costs, a more or less 50% of the reference price assumed for Regulation and Reserve capacity has been considered as reference price for the Reactive Power market, 180 Euro/MWh, with a validity time of one year.

Based on the GAM operation, at the end the day the invoices are generated for each market participant.
Both tests have been performed in a simulated way, through a python script simulating the manual placement of bids and offers by the market participant previously registered.

### 3.4.2. Assessment of the KPIs

The following custom metrics have been defined by the Consortium such as Cost Savings and CO₂ Savings. Those metrics have been populated in a simulated way: bids and offers are posted in the marketplace using a Python script simulating the "manual" posting of market actions.

**Cost savings** metric gives a measure of the economic benefit from participating in the national electricity market (GEM) and to a national ancillary services market (GAM). For GEM, the metric can be computed using the following formulas, differentiated between offers and bids, for each Market Participant.

**CO₂ savings** metric gives a measure of savings in terms of CO₂ emissions coming from trading:

- energy in the local GEM with respect to the same quantity of energy traded in a national electricity market
- services in the local green GAM with respect to the same quantity of service traded in a national market

As the source of energy while buying energy (GEM) or service (GAM) from the utility is not known beforehand, we have made a comparison with CO₂ generation/KWh for known sources, referring to "maximum CO₂ savings".

The indication of the CO₂ savings derived from the marketplace operation only, thus, the DC would trade only renewable energy.

### 3.4.3. Assessment and evaluation of pilot results

#### 3.4.3.1. GEYSER Energy Marketplace

The aim of the test scenario T10/T11 is to evaluate benefits for traders and for the environment coming from the participation into the GEYSER Energy Marketplace (GEM). We have two distinct markets for the results: the Day Ahead and the Intra Day.

GEM introduces an innovative electronic marketplace for energy at local level, enabling bi- or multi-lateral energy trading and transactions among players, not possible so far. GEM is intended for DC and Smart City Energy Actors’ participation in GEM, allowing them to gain additional revenues, exploiting potentially available local flexibility options. Within GEYSER trials, the traded energy will be essentially green, resulting from DCs’ on-site generation, as brown energy sources are assumed to be used only in emergency situations to cover own needs.

Results from tests have proved the cost-effectiveness for buyers in the local GEM, since the energy can be bought at a price lower than the price at which the energy could be bought in the national market. As expected, a local energy market allows to reduce the value chain length and related costs.

The economic benefits for sellers comes, instead, not directly from the sales in the local GEM, but from the incentive offered by the local DSO to sell energy in the local GEM. This incentive is computed as discount percentage on the
local dispatching charges in the bill, which will be lower than national dispatching charges since a local dispatching involves only part of the electrical grid.

Since the GEM is a market where only green energy is traded, it ensures undeniable savings in terms of CO₂.

### 3.4.3.1.1. Day Ahead results

The 5 markets participants – seller – placed up to 4 transactions. The volume of energy sold per seller is up to 3,2 MWh. The costs savings for all actors who have posted sell actions (offers) have a maximum to 32€/MWh, whereas the maximum of CO₂ savings per seller stands at 7 500 lb.

The 5 markets participants – buyer – placed 5 transactions. The volume of energy bought per buyer is around 3,5 MWh. The costs savings for all actors who have posted bid actions ranges between 13€/MWh, whereas the maximum of CO₂ savings per buyer is up to 7 500 lb.

### 3.4.3.1.2. Intra Day results

The 5 markets participants – seller – placed between 10 transactions. The volume of energy sold per seller is around 5 MWh. The costs savings for all actors who have posted sell actions (offers) ranges between 35€/MWh, whereas the maximum of CO₂ savings per seller is ranging to 11 000 lb.

The 5 markets participants – buyer – placed between 8 transactions. The volume of energy bought per buyer is around 4,5 MWh. The costs savings for all actors who have posted buy actions (sellers) ranges between 13€/MWh, whereas the maximum of CO₂ savings per buyer is up to 10 000 lb.

### 3.4.3.2. GEYSER Ancillary Services Marketplace

The aim of the test scenario T12 is to evaluate benefits for traders and for the environment coming from the participation into the GEYSER Ancillary Services Marketplace (GAM).

The test results have proved the economic benefits for the DSO by procuring ancillary services through the GAM, since the service can be bought at a price lower than the price at which the service could be bought in the national market. As expected, a local energy market allows to reduce the value chain length and related costs.

Regarding service providers, the economic benefits from offering their flexibility through the GAM can be increased with incentives from the DSOs, once proved for them the cost-effectiveness of procuring ancillary services through the GAM.

### 3.4.3.2.1. Reserve Ancillary Service results

The 10 market participants – seller – have posted up to 9 transactions, while the volume of energy sold per seller is around 11 MWh. The cost savings for all actors who have posted sell actions (offers) is at a maximum of 320€/MWh, whereas the maximum of CO₂ Savings per seller is of 25 000 lb.
3.4.3.2.2. Regulation Ancillary Service results

The 10 markets participants have a maximum number per seller of 10 transactions, while the volume of energy sold per seller is up to 9 MWh. The Cost Savings for all actors who have posted sell actions (offers) is up to 310 €/MWh, whereas the maximum in CO₂ Savings per seller is 20 000 lb.

3.4.3.2.3. Reactive Power Ancillary Service results

The 10 markets participants have a maximum number per seller of 10 transactions, while the volume of energy sold per seller is up to 12 MWh. The Cost Savings for all actors who have posted sell actions (offers) is up to 180 €/MWh, whereas the maximum in CO₂ Savings per seller is 25 000 lb.
4. Suggestions for improvements towards a market-ready GEYSER solution

The chapter exploits the results obtained with the previous analysis and the results in the various test beds of the GEYSER project.

We gather the different drivers and concerns from the test cases and by consolidating the results, we are going to evaluate the GEYSER Framework and what improvements can be performed to apply the solutions in real-life, meaning a market-ready solution.

4.1. Pilot test bed improvements

4.1.1. RWTH test bed

Even with the conditions of today, every DC can benefit from workload consolidation techniques to reduce energy consumption. For consolidation DCs the main risk is managing the clients’ workload. This was further explained in the roadmap.

For T01, the use of more physical servers would have been required to really test the behaviour of the system.

As for T02 the results are highly dependent on the percentage of delay-tolerant workload that the DC has during one day and on the variability of the IT workload profile. Even with the conditions of today, every DC can benefit from shifting delay-tolerant workload to reduce Economic Expenses.

Regarding the deployment process, difficulties arisen on training the prediction module of the Optimizer due to limited time after deployment and caused estimation errors. Before going on real-life, the prediction module should be accurate enough and additional protection of the equipment must be ensured.

For future applications, the KPIs should be computed after execution of the action, this is, considering real-time monitoring data. It is necessary to improve KPIs to reflect useful work performed.

Even with the conditions of today, medium to large size DCs can reduce Economic Expenses with the operation of batteries to partially power the DC. However, the lifetime of the batteries is reduced. In situations when the full power output of the batteries is larger than the DC consumption the DC could fed-in the remaining energy to the Smart Grid in exchange for an economic reward, for which Market presence is needed. In general, the regulatory framework makes it challenging for prosumers to participate and contribute to high-level Smart Grid goals.

Assuming that there exists a substantial reward scheme from the DSO, medium to large size DCs can reduce Economic Expenses operating the local generation devices. As mentioned before, it is generally not cost effective to operate back-up generators in DC facilities to fed-in the grid, but under strong fluctuations in the grid-load.
characteristic, the DC could operate the diesel generator by request from the DSO. For this, there is a need for market presence.

Up till now, it is not easy to evaluate the possible savings that operating the generator could bring, since this is highly dependent on the DSO’s reward scheme, as described previously, for which very little information is available. A clear need for Market presence was identified. As future work, a complete economic study on the DSOs’ reward schemes in Europe should be conducted as part of future EU projects as well as the exploitation plan of the GEYSER solution.

4.1.2. Alticom test bed

The GEYSER project learned at Alticom that there is more to energy provisioning for a DC than meets the eye. More than before participating to the project, Alticom now has a good view on difficulties in energy provisioning and balancing the energy grid in a smart city environment for a DSO. This enables Alticom to take a(n) (active) role in the future energy transition in which producers and consumers in a Smart City environment work closely together maximize the use of renewable energy and to balance a regional grid.

Functioning of GEYSER is influenced by specific parameters of the DC. The layout of the DC, the installed cooling systems, as well as potential heat storage components (air volume at Alticom) are very specific. Due to these “custom made” changes, as well as the integration with the existing DCIM, more time was needed for the preparation as initially planned.

The basic functions however are well equipped to meet these challenges. Apart from switching on/off the cooling installation, more flexibility could be realised if ventilator speed could be altered, or cooling installations would have multiple operation modes (0, 25, 50, 75, 100 percent). The more specific the configuration of GEYSER to the DC, the better the leveraging possibilities are on non-electrical cooling mechanisms in place.

4.1.3. PSM test bed

If we consider a local energy market and an ancillary service market, we have different factors that can improve the ESS value metric. For example, in a local market, when there is a high-energy demand (with correlated high electricity prices) or there is critical condition in technical operation, DSO can incentivise the DC for islanding operation.

4.1.4. Terni test bed

The simulated scenarios have delivered good results for both the GEM and the GAM and the metrics computed were defined especially for these test cases. In order to have a bigger impact for the results, the improvement would be to define a "global" metric that would provide information on the benefit of trading in the marketplace.

A metric to evaluate the environmental impact of the scenarios implemented where we have access to the DC information to actually assess the CO₂ savings and also to evaluate the financial impact where we can stipulate that the revenue generated from the test scenario outweigh the cost.
4.2. Creating a roadmap towards a market-ready solution

4.2.1. Environmental

The environmental perspective regarding our pilots have been assessed through the evaluation of the KPIs of the different test cases.

In all the test cases, we can say that the **PUE decreased**, considering when the test starts and after the test was concluded, meaning that we used less power for the IT Equipment in contrast to the facility. An average between 1,2 and 1,7 in the PUE metrics has been computed in the test cases. Some factors can explain a high PUE such as the fact that some was emulated to have the normal condition of the DC or the fact that some test case was emulated, it was not possible to test in real life. Considering the proof-of-concept implemented and tested throughout few months, this result is very promising to perform more test to improve the PUE and be as efficient as possible. For the HPC DC – in the Aachen test bed –, when performing the test cases on IT Workload, the PUE remains almost unchanged, between 1,67 and 1,70; as well as for using the GEYSER ESP to evaluate the optimization plans before real-life execution in T07 and T08. The PUE of 2,1 in Colo DC of Alticom was emulated and under dx-cooling conditions and that under normal conditions, the DC has a PUE of less than 1,2 thanks to free air cooling. Regarding the Colocation DC of PSM, the PUE during the test decreases since by switching off the refrigerating units the Total Facility Power is lower, from 1,5 to 1,2.

The second most valuable KPI to assess the environmental benefit of the GEYSER Solution is the **CO₂ Savings** where we measure the percentage of savings in terms of CO₂ emissions generated by a DC, once improvements have taken place regarding its energetic, economic, or environmental management. We have successfully reached up to 16% in CO₂ Savings between all the test cases. The reduction of the CO₂ emissions is a key data not only for a DC Manager but also for a Smart City Manager as it is involved in the development of sustainable policies within the Smart City context. The electrical cooling devices test cases – T04 and T05 – in the Alticom test bed has the most valuable result of about 16% in CO₂ savings as this is closely related to the PES up to 40%. Shifting the workload is environmentally beneficial to achieve greater results. The thermal storage capacity and inertia, as well as the cost-effectiveness are closely related to reduce CO₂ savings, ranging from 2,5% to 4,7% in 2 different tests. The intelligent planning of back-up generator maintenance run and production of energy during the test allow the DC to save up to 4,5% in CO₂. The type of Medium Enterprise DC doesn’t interfere with the results as these tests were virtual. CO₂ savings in the practices related to the GEM Marketplace have been assessed since the GEM is a market where only green energy is traded, it ensures undeniable savings in terms of CO₂.

Moreover, based on the environmental assessment of the DC tested, the **savings in PES** is important to consider because it measures the percentage of savings in terms of primary energy consumed by a DC, once improvements have taken place with regard to its energetic, economic, or environmental management. As an average in the test beds where it has been computed, we are able to reach 40% of primary energy savings. In a Colocation DC that run on normal condition, using the thermal storage an inertia allow a PES between 6% and 10%. The cooling flexibility reaches 40% of PES with a small IT load on a Colo DC.
4.2.2. Economical

The economical consideration for any stakeholders that has been identified within the GEYSER project is based on the Economical Expenses computed in the test cases. We have noticed exceptional results in term of EE, mainly in the cooling related test case with a value up to 35%! In the other test cases, we showcased an average between 2 and 15% in EE, which is still very promising for any stakeholders’ wishes to implement the GEYSER Framework. For the IT Workload actions, the economical expenses are strongly related to first the consolidation while a decrease in the DC power consumption enables a reduction of 12 to 15% in the EE and second, by shifting the workload at peak times and at low energy price, it resulted between, 2,5 and 10% in the EE. When it comes to a dynamic cooling, it also resulted in economic savings up to 35% by optimizing the cooling system. A cooling water system is also closely related the CO2 savings ranging from 2,5% to 4,7% because we consider the energy cost as constant during the test.

Regarding the GEM marketplace, the financial impact for the buyers comes from the local energy market where the energy is bought at lower price than the national energy market, as for the sellers, the economic benefits are possible through incentives offered by the local DSO to sell energy in local GEM. Test results have proved the economic benefit for the DSO to procure ancillary services through the GAM, since the service can be bought at a price lower than the price at which the service could be bought in the national market. As expected, a local energy market allows to reduce the value chain length and related costs. Regarding service providers, the economic benefit from offering their flexibility through the GAM can be increased with incentives from the DSOs, once proved for them the cost-effectiveness of procuring ancillary services through the GAM.

4.2.3. Technological

As output of a research project, the GEYSER Solution which have been successfully tested in various test-beds will need couple of years to mature and to make the deployment process better. The research development is one thing, the market-ready is a different one. After the completion of the project, we have identified various partners that are ready to adopt this technological solution and implement in their DCs. This will bring more opportunities to work on this Solution and improve it.

To better evaluate all the components integrated to the GEYSER Solution, all the tests must be carrying out for a longer period to achieve almost real results. As some of the tests were virtual, a real-life test must be carrying out for some the test such as T06, T07, T08 and T09.

One other point that has been raised during the GEYSER General Meeting held in Dublin last September, even if the Optimizer is able to points out (and makes actionable) opportunities for e.g. energy saving, money saving, supporting the grid, etc. there is still needed a higher degree of automation when comes to actually controlling and enforcing the actions. Following the trends from the industry, a higher degree of automation can save time but concerns about the complexity of such a tool and DC manager fear of losing control need to be toughly addressed.

When it comes to adopt the Business Framework of the GEYSER Solution after the completion of the project, it would be best to implement a smarter signalling system and more changes. Accordingly, to each type of DC and because 2 DCs are not the same, DC managers should be able to match their needs with the GEYSER solution, otherwise it is not interesting to implement it is the focused criteria is not referenced in the core system of the solution. Altimocom is proactively using free air cooling and they have designed their Colo DCs in an innovative way. Therefore, when performing T04 and T05, they could not change the cooling temperature as they wish, which is
settled between +/- 2 degrees. Another example would be to allow for a large window of increased temperature; i.e.: up to 2 hours instead of 30 minutes.

Different types of flexibility action are suitable for HPC DCs but also for Big warehouse DCs, as well as Enterprise DCs, the applicability issues for Collocation DCs are related to (negatively) impacting service provisioning. That is why, one of the recurring recommendations based on the experiments carried out in the pilots’ sites is that: the design of the DC should offer flexibility; e.g., by building thermal buffers into the design or actuating energy storage/generation equipment. The tests performed are the first experiments and that is why it is important to explore this consideration, if we want the flexibility to be the core value of a DC.

As for Colo DCs it is a fact that they do not have any control over the IT equipment as this owned by their customers but they do have control over the non-IT equipment (local generators, cooling devices, thermal storage, etc.); the latter are also flexibility components. Therefore, a Colo DC needs to guarantee enough power to their customers to ensure the reliability of their business and to be able control such components to exploit their energy flexibility and participate in smart city integration schemes.

In most of the test cases, the KPI related to the evaluation of the capability of a DC to change its energy consumption behaviour, namely the DCA, remains stable with an average of 0,90 out of 1 when it comes to thermal storage and maintenance of back-up generators, meaning that the DC adapts slightly to changes; and around 0,6 for the dynamic cooling, meaning that the DC adaptability is relatively high.

4.2.4. Social

During the previous General Meeting held in Dublin last September, the partners of the Consortium made relevant comments about the level of adoption for the GEYSER Solution. Indeed, DC’s are less enthusiastic about adopting the different GEYSER modules than DSO’s, Energy Providers or Smart City stakeholders. For future adoption, there will be need to have different story for implementing the Solution by the diversity of stakeholders that we have targeted in this project. The different offerings of the GEYSER Solution will not be the same for an ESCO, Smart City Manager or DCs M&O so we should adapt the way we will sell it to better match our stakeholders’ expectations.

Another social driver for the next 5 to 15 years is the shift towards exploiting more flexibility from the cooling devices to trade with a prosuming activity (Smart City integration). Currently, every DC can perform that but for the Colo DC it is another story as their first business is to sell this IT load’s flexibility, costumers might think it could be a risk for their data to be integrated in the Smart City environment. The mind-set needs to change to be socially acceptable and as far as the project evolve, being able to store extra energy could raise awareness among DCs actors and especially Colo DCs. A standard based on this flexibility could also be the start for Colo’s to start exploiting and sharing this flexibility.

There was no “social KPI” to compute but this is not a problem because the assessment of the different test scenarios were based on a proof of concept of a technological and innovative DC development. Suggestions for assessing social drivers could be the time allocated to install, configure, run and evaluate the solution and especially the deployment process of the Optimizer for example. Before going on real-life, the prediction module should be accurate enough and additional protection of the equipment must be ensured.
5. Conclusions

This deliverable concludes the results of the pilots and performs an analysis to consolidate take-aways and suggestions for a market-ready solution, following the test description, evaluation and solution assessment in the German Testbed (D7.4), Dutch Testbed (D7.5), Pont Saint Martin Testbed (D7.2) and Terni Testbed (D7.3).

Satisfactory results in terms of Energy Savings and Economic Expenses were obtained in almost all the pilots. Even though some test cases have been simulated, this does not interfere with the quality of the results we have obtained from successfully deploying all modules pertaining to the GEYSER Solution.

When considering the financial and environmental impact of a DC, it is necessary to take into account different perspective and aspects where the type of a DC might affect these results. This is why we have chosen to create different mapping analysis based on the type of the DC (Colo, HPC, and Enterprise) where the results will be achieved.

The results from the different mappings based on the SIAM analysis allow a relevant visualisation of the different test scenarios that are of importance when considering higher workload flexibility, interaction with the Smart City, dynamic cooling environment and so on. The correlation between different set of stakeholders, drivers and KPIs enables a comprehensive approach to the implementation of the practice where the 4 main environments (Social, Economic, Environmental and Technological) gives quantitative and qualitative impact to consider.

The experiments conducted in the testbeds along with the achieved performance deliver proof that indeed the developed GEYSER framework can mature into a commercially viable market solution in the coming years. We strongly believe that this innovative and flexible solution can and will be part of further strategies, embedded in urban development. The GEYSER solution does indeed support green DCs to fully exploit their energy flexibility and interact with their local grid and Smart City environment to either save energy related costs or even create financial revenue by participating in local energy marketplace(s).
6. References


APPENDIX A. PESTEL-GS Data Collection Questionnaire

**P** - Which drivers (with relevance to 4 ESTE dimensions) can be identified that are key to the organisation?

Notes: Examples: Energy efficiency; financial performance; leadership / innovation; skill; knowledge development; job satisfaction; corporate social responsibility; positive customer experiences etc.

**E** - What are the economic objectives that may impact the decision-making?

Notes: Objectives are (preferably) linked to the drivers mentioned under P but are specified as a target to meet.

*Relates to: [Value Interests Economic Dimension in 4D/SoSA model]*

**S** - Which social factors may impact the Smart City environment and the decision-making process?

*Relates to: [Value Interests Social Dimension in 4D/SoSA model]*

**T** - What are the technological innovation(s) need to be taken into account for the market structure?

*Relates to: [Value Interests Technology Dimension in 4D/SoSA model]*

**E** - What are the environmental drivers and concerns for the sector(s) involved? And who are the relevant stakeholders?

*Relates to: [Value Interests Environmental Dimension in 4D/SoSA model]*

**L** - Which governmental or organisational policies may impact the decision-making of the pilots at the EU level?

Notes: Think of policies related to energy targets, Smart City, DC, etc.)

**G** - Who are the main actors of the environment where the practice is applied?

**S** - What are geography-related factors that need to be taken into account?

*Note: F.e. elevated / below sea-level, infrastructure, city’s boundaries, type of landscape (flat/mountainous).*