Cloud Orchestration at the Level of Application

Project Acronym: **COLA**

Project Number: **731574**

Programme: **Information and Communication Technologies**
Advanced Computing and Cloud Computing

Topic: **ICT-06-2016 Cloud Computing**

Call Identifier: **H2020-ICT-2016-1**
Funding Scheme: **Innovation Action**

Start date of project: 01/01/2017 Duration: 33 months

Deliverable:

D1.5 Final Project Report

Due date of deliverable: 30/09/2019 Actual submission date: 20/11/2019

WPL: Gabor Terstyanszky

Dissemination Level: PU

Version: final

Contents

List of Figures and Tables

Figures

Tables

Status, Change History and Glossary

Status:	Name:	Date:	Signature:
Draft:	Gabor Terstyanszky	21/10/19	Gabor Terstyanszky
Reviewed:	Tamas Kiss	30/10/19	Tamas Kiss
Approved:	Tamas Kiss	31/10/19	Tamas Kiss

Table 4 - Status Change History

Version	Date	Pages	Author	Modification
v1.0	30/09/19	10	G Terstyanszky	report template
v1.1	12/10/19	2	G Terstyanszky	WP1 activities and achievements
	14/10/19	3	J M M Rapun	WP8 activities and achievements
	15/10/19	1	G Pierantoni	WP5 activities and achievements
	15/10/19	2	V. Zakharenko	WP3 activities and achievements
	15/10/19	2	B Despootov	WP4 activities and achievements
	15/10/19	2	J Kovacs	WP6 activities and achievements
	16/10/19	2	T Carnehult	WP7 activities and achievements
v2.0	17/10/19	8	G Terstyanszky	how COLA objectives were achieved
	17/10/19	6	G Terstyanszky	impacts COLA generated and will generate
	20/10/19	6	A Ocklenburg	WP2 activities and achievements
v3.0	21/10/19	14	WP Leaders	revision of text on objectives and work package activities
	22/10/19	6	G Terstyanszky	summary on efforts and budget used
v4.0	24/10/19	34	G Terstyanszky	first complete version of D1.5
final	26/10/19	36	T Kiss	internal review

Table 5 - Deliverable Change History

Glossary

ATF	Application Task Force
ADT	Application Description Template
EAC	Ethical Advisory Committee
IAB	Industrial Advisory Board
PMB	Project Management Board
TMB	Technical Management Board
PC	Project Coordinator
PM	Project Manager
PQM	Project Quality Manager
TMB	Technical Management Board
TTF	Technical Task Force

Table 6 – Glossary

1. Introduction

Cloud computing has successfully and steadily addressed issues of how to run applications on complex distributed computing infrastructures. On-demand access to cloud resources in a flexible and elastic way could result in significant cost savings due to more efficient and convenient resource utilization. However, the efficient and dynamic utilization of Cloud is not trivial. The take up of cloud computing in some application areas is still relatively low due to limited application-level flexibility and shortages in cloud specific skills. Public sector organizations and SME are increasingly considering using the Cloud in their everyday activities but they still face difficulties of both economic and technical nature. To enable the execution of applications in the Cloud in a cost effective, flexible and secure way, applications must be deployed, executed and removed through a framework that hides cloud specific details from users. COLA addressed the following challenges:

- describing the topology of containerized/virtualized applications and their policies to control their lifecycle in a cloud agnostic way,
- supporting deployment and run-time orchestration and optimisation of such applications taking various QoS parameters into account, and
- creating and running near production level applications in the Cloud.

COLA developed the MiCADO framework to process application descriptions, to deploy and execute them in the Cloud. COLA developed the TOSCA based Application Description Template (ADT) to specify applications and their policies. ADT enables application descriptions based on two-level topology (Container-level and Virtual Machine-level) and adding security- and scaling-related policies. ADTs are forwarded to the MiCADO Submitter that parses and validates ADTs and forwards them to adaptors, such as container adaptor, cloud orchestration adaptor and policy keeper adaptor. The orchestrators create and launch virtual machines and containers specified in ADTs. The MiCADO Policy Keeper scales up and down virtual machines and containers using cloud (e.g. Occopus or Terraform) and container orchestrator (e.g. Docker Swarm or Kubernetes) based on the information gathered by the Prometheus monitoring, recommendations provided by the MiCADO Optimizer and TOSCA policies specified in ADTs. The MiCADO Security Policy Manager handles security policies given in ADTs through security enablers. The MiCADO framework can be deployed as Ansible playbook to make deployment effortless as much as possible. To support application developers and end users MiCADO was extended with a dashboard including Docker Visualizer, (replaced by Kubernetes dashboard later), Prometheus. COLA elaborated 3 near production level applications and 26 proof of concepts demonstrators.

COLA Description of Work (DoW) specifies Deliverable 1.5 “Final Project Report” as follows: This report will compile the final report of the project’s achievements in the development of the MiCADO framework and implementation of COLA use cases and proof of concepts demonstrators.

Deliverable D1.5 is structured as follows:

Section 2 - describes how COLA met objectives specified in COLA DoA.
Section 3 - outlines activities and achievements of COLA work packages.
Section 4 – explains how COLA generated and will generate impacts through the MiCADO framework and COLA use cases and proof of concepts demonstrators.
Section 5 - describes changes and modifications in COLA, how the project partners addressed reviewers’ comments and human resources are used and how the project budget was spent.

2. Explanation of the work carried out by the beneficiaries and overview of the progress

2.1 Objectives

Objective 1: Designing, prototyping, testing and demonstrating a set of services in a generic framework that cloud application developers can utilise from their application source code in support of developing highly scalable and dynamic cloud applications.

The COLA project will utilise available low level container-based technologies, open source cloud orchestration solutions and monitoring tools, and existing cloud standards for topology and orchestration specification to prototype, test, demonstrate and pilot a pluggable cloud service optimisation framework that is easily applicable by application developers. Using MiCADO services in application logic will result in more flexible and resource-effective cloud solutions. The project will design and implement the multi-layered MiCADO architecture based on the concept of microservices to enable plugging in multiple technological components when fulfilling a specific task and to avoid dependence from a particular technology. Measurable indicators of Objective 1 are collected in Table 2.1.

Objective 1 indicators – COLA achieved by M33

WP	Measurable Indicator	targeted	M01-M18	M19-M33	M01-M33
WP5 WP6 WP7	MiCADO prototype reference implementations developed, tested and demonstrated.	2	6	9	15
WP5 WP6 WP7	Peer reviewed publicatons on the generic MiCADO framework concept and its implementation.	6	7 conference, & 7 journal papers and 1 book chapter	2 conference, & 4 journal papers	9 conference & 11 journal papers and 1 book chapter

Table 2.1 - Measurable indicators of Objective 1

COLA developed MiCADO as a generic pluggable framework that supports optimal deployment and run-time orchestration of applications in the Cloud. It is based on existing low-level cloud container technologies (e.g. Docker), management and orchestration solutions, and existing standards (e.g. TOSCA) with well-defined standardised interfaces to avoid dependence on one particular cloud technology. The first MiCADO releases used Occopus as cloud orchestrator and Dock Swarm as container orchestrator. In later releases Kubernetes replaced Docker Swarm as container orchestrator. COLA also created a proof of concept implementation in which Terraform is used as cloud orchestrator. These developments confirm that the MiCADO framework is generic and pluggable, i.e. its services are not restricted to particular technologies and can be implemented using different technologies and services. MiCADO provides the missing link between existing non-cloud aware applications and the dynamic capabilities of IaaS Clouds by allowing connecting to multiple technology implementations on demand. It can access multiple cloud middleware (e.g. Amazon EC2, CloudSigma, Microsoft Azure, OpenStack and OpenNebula) and generic cloud access layers (e.g. CloudBroker Platform).

MiCADO processes TOSCA based application descriptions, deploys and executes them using these descriptions in the Cloud. First, the MiCADO Submitter parses and validates the Application Description Templates (ADT) and forwards them to adaptors, such as container adaptor, cloud orchestration adaptor and policy keeper adaptor. The cloud and container orchestrator creates and launches virtual machines and containers specified in ADTs. The MiCADO Policy Keeper scales up and down virtual machines and containers using cloud (e.g. Occopus or Terraform) and container orchestrator (e.g. Docker Swarm or Kubernetes) based on the information gathered by the Prometheus monitoring, recommendations provided by the MiCADO Optimizer and TOSCA policies specified in ADTs. The MiCADO Security Policy Manager handles security policies given in ADTs through security enablers. The MiCADO framework can be deployed as Ansible playbook to make deployment effortless as much as possible. To support application developers and end users MiCADO was extended with a dashboard including Docker Visualizer, (replaced by Kubernetes dashboard later), Prometheus and Grafana to provide information about the application executed by the MiCADO orchestration layer.

COLA launched MiCADOscale, based on the MiCADO framework, for businesses. COLA project partner CloudSME, in collaboration with SZTAKI and UoW, offers consultation and support for setting up, developing and managing

services in the Cloud including cloud native application development, creating Application Description Templates and prototyping customized application in the Cloud. MiCADOscale can also deliver improved server capacity utilisation and greater flexibility with reduced total operating costs.

The project designed, implemented, deployed, tested and released 9 versions of the MiCADO framework in M19-M33. WP6 described these releases in deliverable D6.4 "Prototype and documentation of the price/performance optimization service". The major new features of these releases are listed below:

- MiCADO v0.5.0 – TOSCA support, user-defined scaling policy support, new dashboard with Docker Visualizer, Grafana and Prometheus, Ansible deployment;
- MiCADO v0.6.0 – Security Policy Manager (firewall, proxy, authentication, authorisation) added, new submitter query functions, improvements on cloud handling and user experience;
- MiCADO v0.6.1 –extending Application Description Templates and improving its translation;
- MiCADO v0.7.0 –Kubernetes replaced Docker Swarm as container orchestrator;
- MiCADO v0.7.1 – upgrading the MiCADO framework for Kubernetes v1.13.1;
- MiCADO v0.7.2 and v0.7.2 rev1- direct translation from TOSCA to Kubernetes Manifest to support Kubernetes workloads such as DaemonSets and Jobs to provide better configuration for exposing Pods;
- MiCADO v0.7.3 – moving core MiCADO services from static Docker containers to Kubernetes Workloads and supporting multiple set of worker nodes.
- MiCADO v0.8.0 – MiCADO Optimizer has been added to the MiCADO framework.

WP8 used the MiCADO framework to develop and run COLA use case applications: use case 1 (audience finder application), use 2 (evacuation simulation) and use case 3 (social media analytics to improve citizen services) in the Cloud and elaborate the COLA proof of concepts demonstrators.

WP5-WP6 published 2 paper in conference proceedings and 4 papers in journals on TOSCA based application descriptions and the MiCADO framework in M19-M33.

Objective 2: Piloting, demonstrating and validating the technical feasibility of the MiCADO framework in SME and public sector case-studies.

The project will analyse SME and public sector use cases that require highly flexible and resource effective cloud solutions. COLA will pilot and demonstrate the applicability of the MiCADO framework when optimising these application scenarios to utilise the scalable, flexible and elastic capabilities of cloud infrastructures. The project will develop demonstrators in real-life operational settings for typical and demonstrative application scenarios by both SMEs and public sector organisations where efficiency of the cloud solution will be significantly improved via MiCADO. The selected use-cases represent a wide range of typical application areas of the SME and the public sectors, and have the potential of making significant impact in the represented areas well beyond current project partners. As an output of the project three full scale demonstrators and twenty further proof-of-concept prototypes will be implemented. Measurable indicators of Objective 2 are collected in Table 2.2.

Objective 2 indicators – COLA achieved by M33

WP	Measurable Indicator	targeted	M01-M18	M19-M33	Total
WP8	Number of analysed SME and public sector use-cases that require highly flexible and resource effective cloud solutions	23	3 COLA use cases and 10 proof of concepts demonstrators	16 further proof of concepts demonstrators	3 COLA use cases and 26 proof of concepts demonstrators
WP8	Fully developed demonstrators in real-life close to operational settings.	3	prototypes of 3 COLA use cases	near production version of 3 COLA use cases	near production version of 3 COLA use cases
WP8	Proof of concept demonstrators for real-life use-cases of COLA technology provider partner customers (customers of Saker, CloudSME UG, Inycom and Outlandish)	20	feasibility studies of 10 proof of	feasibility studies of 16 proof of	feasibility studies of 26 proof of

			concepts demonstrators	concepts demonstrators	concepts demonstrators

Table 2.2 - Measurable indicators of Objective 2

WP8 further improved the implementation of the COLA use cases reaching a near production version:

- use case 1: audience finder application (Outlandish + The Audience Agency);
- use case 2: evacuation planning (Saker + Brunel University);
- use case 3: social media analytics to improve citizen services (Inycom + SARGA).

Running these applications through the MiCADO framework leads to better performances, more optimal resource usage, more cost efficient and lower operational costs. This framework enabled application developers to describe, deploy and run these applications in the Cloud. Application developers provided feedback on the MiCADO framework to guide its development to support running commercial and public service applications in the Cloud. Application Developers consider this framework as flexible and generic enough to support different types of requirements. See details of these implementations in deliverable D8.3 "COLA near to operational level pilots and demonstrators".

COLA identified several application domains that require highly flexible and cost effective cloud services that the MiCADO framework can offer. WP8 selected and elaborated proof of concept demonstrators of the following 26 applications:

high-performance modelling and simulation

- evacuation service, high-performance digital twin simulation analytics, discrete event simulation in manufacturing to support decision making using MAGOS, discrete event simulation to optimize manufacturing using JaamSim, agent based model simulation (ABM) using REPAST, agent-based micro-simulation using PALM, agent-based simulation using FLEE. High Speed Simulation Analytics using D-SIMLAB;

Artificial Intelligence

- clinical mammography using CAROL as deep learning;

social media

- managing social media presence using Social Monitor;

web applications

- using feature branches in website development, managing school cuts in public funding using School Cuts, optimizing website hosting through shared hosting;

web monitoring and alerts

- Competitors Alerts ;

data analytics

- Attendance Analyzis Service, extending Audience Finder to new sectors, Extending Audience Finder to new countries;

Internet of Things / Smart Cities

- predictive analysis of the evolution of assets-related KPIs using MainRail, CityMOS simulation;

remote storage

- data management in cloud storage using DataAvenue;

scaling applications in the Cloud

- Autoscale as a Service (AaaS);

cloud hosting

- MiCADOscale HKN, NextCloud, WordPress HKN;

software testing

- testing software applications using the Integrated Testing Solution, evaluating application status;

25 of the 26 demonstrators are presented in deliverable D8.4 "Proof of Concept Feasibility Studies". COLA predicts that these applications will bring new economic benefits including over EURO 2 Million in additional revenues. TRLs of these demonstrators show that most of these will be close to commercial production in 2 years after the end of the project.

WP8 published 1 paper in conference proceedings, 2 papers in journals and 1 paper in a book chapter on how to use the Cloud to run applications in M19-M33.

Objective 3: Validating economic feasibility of the implemented use-cases.

Besides the technical implementation, COLA will analyse and validate the economic feasibility of applying MiCADO services when improving the efficiency of the selected representative SME and public sector case-studies. Aspects and implications of increased performance, reliability and scalability, and optimisation of costs will be considered and measured. The economic impact of the implemented cloud-based solution will be quantified and clearly highlighted for the selected use-cases. Measurable indicators of Objective 3 are collected in Table 2.3.

Objective 3 indicators – COLA achieved by M33

WP	Measurable Indicator	targeted	M01-M18	M19-M33	M01-M33
WP3	Economic impact and feasibility of fully implemented demonstrators in real-life close to operational settings is analysed.	3	study of 3 COLA use cases and 1 demonstrator	0	study of 3 COLA use cases and 1 demonstrator
WP3	Economic impact and feasibility of proof of concept demonstrators is analysed.	20	0	study of MiCADO scale and 26 proof of concepts demonstrators	study of MiCADO scale and 26 proof of concepts demonstrators

Table 2.3 - Measurable indicators of Objective 3

COLA followed a binary marketing approach to MiCADO, i.e, dividing MiCADO brand into two sub-brands, MiCADOscale, the commercial brand, and MiCADOcommunity, the open source brand, considering that academic and commercial communities have different set of requirements. WP3 defined and illustrated the commercial potential, economic impact and value of MiCADOscale using business model and value proposition canvas. The work package also developed the sustainability plan for MiCADOscale. The commercial potential, economic impact and sustainability of MiCADOscale was described in deliverable D3.3 "Final commercial exploitation and sustainability report". Further, deliverable D8.4. "Proof of Concept Feasibility Studies" described expected economic and technical impacts and TRL levels of 24 proof of concepts demonstrators.

WP3 in cooperation with WP4-WP8 planned and ran a successful marketing campaign. Promotion of the project results at different events increased the awareness about MiCADO. Metrics and KPIs of the marketing campaign were measured and analysed, the necessary adjustments to the campaign were made. Potential customers and interested parties were identified, communication channels with them were set up. Marketing activities after the end of the project were planned and are ready to be executed.

Objective 4: Defining common and widely applicable application templates.

COLA will investigate and develop application definitions for common cloud-based application scenarios. Derived from the requirements of its real-life case-studies, the project will define common application templates and identify how these templates can be mapped to typical real life use-case scenarios within and beyond the project. It will develop a template description language based on existing standards, such as the Tosca standard by OASIS, and it will store and describe these templates with rich metadata in a suitable repository from where companies can use them to quickly port their applications into clouds in a scalable, secure and robust way. Measurable indicators of Objective 4 are collected in Table 2.4.

Objective 4 indicators – COLA achieved by M33

WP	Measurable Indicator	targeted	M01-M18	M19-M33	M01-M33
WP5	Template and application description language developed.	1	ADT concept	upgraded ADT concept	upgraded ADT concept
WP5	Common, widely applicable application templates defined and described.	6	1 policy and 2 topology ADT skeletons	7 policy and 4 tests ADT skeletons	8 policy, 4 test and 2 topology ADT skeletons
WP8	Application templates validated via the implementation of real-life case-studies.	4	3 COLA use case ADTs	3 ADTs for COLA use case and 24 ADTs for	3 ADTs for COLA use case and 24 ADTs for

				proof of concepts demonstrators	proof of concepts demonstrators
WP5	Peer reviewed publications on application description and ttemplates	2	3	none	3

Table 2.4 - Measurable indicators of Objective 4

WP5 developed the concept of the TOSCA based Application Description Template to specify applications and their policies for the deployment and execution on cloud infrastructures. ADT extends TOSCA to define application descriptions based on two-level topology (Container-level and Virtual Machine-level). WP5 also expanded the TOSCA policy specification adding several security- and scaling-related policies. To support standardization and interoperability, the ADT is technology agnostic, (i.e. it specifies functionalities of the application but no assumptions are made on how these functionalities will be implemented). The MiCADO Submitter translates the information contained in ADT into the specific syntaxes required by the various components of the MiCADO framework, for example for cloud orchestrators, container orchestrators, policy keepers, etc. This approach resulted to be successful in achieving the required flexibility. As an example, modifying ADTs from Docker Swarm to Kubernetes took only minor efforts.

COLA elaborated several generic and application specific ADTs. WP5 and WP6 developed 2 generic topology skeletons (Docker Swarm and Kubernetes), 6 generic policy skeletons (consumption, cost constrained deadline and performance based scaling policy and connection, location and resource deployment policy) plus 2 specific security skeletons (to comply with WP7 requirements): Proxy settings and handling of secret information. 2 other security-related policies to support AuthN and AuthZ that were originally designed proved not to be necessary as these aspects are handled directly by the applications. To support testing WP5 wrote four ADTs (cQueu/jQueuer, NGINX, stressing and WordPress ADT). WP5 and WP8 created two types of application specific ADTs: 3 ADTs to describe 3 COLA use cases and further 26 ADTs to specify COLA proof of concept demonstrators. All these ADTs are uploaded and available in the MiCADO Repository hosted by GitHub. Deliverable D5.5 “Second Set of Templates and Services of Use Cases” describes both the generic and application specified ADTs.

WP5 published 1 conference paper to disseminate the ADT concept in M19-M33.

Objective 5: Providing access to heterogeneous, federated and distributed cloud resources.
MiCADO services will interface with a wide variety of heterogeneous and distributed cloud resources. MiCADO will be connected to the CloudBroker Platform, the commercial offering of CloudBroker GmbH and integral component of the CloudSME Simulation Platform (developed in the FP7 CloudSME project and now exploited by COLA project partner CloudSME UG) that provides access to multiple heterogeneous cloud solutions based on a variety of cloud middleware. Connection to direct cloud APIs and to cloud federations (e.g. EGI Federated Cloud) will also be supported. The resulting solution will facilitate the utilisation of cloud resources from multiple IaaS clouds and/or the seamless migration of applications between different commercial or private cloud resource providers. As a result by using the MiCADO services companies can avoid cloud vendor lock-in. Measurable indicators of Objective 5 are collected in Table 2.5.

Objective 5 indicators – COLA achieved by M33

WP	Measurable Indicator	targeted	M01-M18	M19-M33	M01-M33
WP4	Types of IaaS clouds supported by the reference implementation of the MiCADO framework.	8	3 private and 3 commercial clouds	2 additional commercial clouds	3 private and 5 commercial clouds
WP8	Seamless application migration between different private and public cloud resource providers is demonstrated.	4	0	3 COLA use cases and Data Avenue demonstrator	3 COLA use cases and Data Avenue demonstrator

Table 2.5 - Measurable indicators of Objective 5

To offer more cloud resources for application developers and end users CloudBroker and CloudSigma provided access to two more commercial clouds: HKN and Microsoft Azure in M19-M33. As a result, the MiCADO framework provides access to the following academic and commercial clouds:

academic clouds:

- OpenNebula with EC2 interface at SZTAKI and
- OpenStack with Nova interface at RISE and UoW;

commercial clouds:

- Amazon with EC2 interface;
- CloudBroker;
- CloudSigma
- HKN and
- Microsoft Azure.

WP4 set up and managed the COLA development infrastructure that incorporates all the above listed clouds. WP5-WP7 used this infrastructure to test the MiCADO framework's services, such as the MiCADO Submitter, the MiCADO Policy Keeper, the MiCADO Security Enforcer, etc. First, COLA use case owners with WP4-WP7 technical support deployed and ran the COLA use case applications on the development infrastructure to create the first prototypes. Next, they migrated these applications to the following cloud infrastructures:

- use case 1: audience finder application - on CloudSigma and AWS;
- use case 2: evacuation planning - on CloudSigma, AWS and Microsfot Azure;
- use case 3: improving services for citizen using social media analytics - on CloudSigma and AWS.

The COLA proof of concept demonstrators were tested on the COLA development testbed using academic clouds, such as RISE, SZTAKI and UoW cloud. Some of these applications were migrated to other clouds. The best example is the Data Avenue demonstrator that was tested on the SZTAKI cloud built on OpenNebula and migrated to CloudSigma.

Objective 6: Developing solutions to address security, reliability and trustworthiness of MiCADO services in the context of application migration between different cloud resources.
COLA will specifically address issues of security, reliability and trustworthiness in relation to the developed MiCADO services. Specific security problems and aspects of dynamic scaling of cloud infrastructure resources and application migration between resources of a particular cloud, a cloud federation, or distributed heterogeneous clouds will be investigated and solutions will be developed. Advanced security policy management mechanisms will be built at orchestration level that will decouple the detailed security management from application developers. Developers and application domain owners will only provide high-level security policies and security credentials, and will use high level APIs to "mark" security levels of applications and/or data that applications handle. These inputs will be used by an enforcement layer to apply the security policies at the orchestration level. Measurable indicators of Objective 6 are collected in Table 2.6.

Objective 6 indicators – COLA achieved by M33

WP	Measurable Indicator	targeted	M01-M18	M19-M33	M01-M33
WP7	Advanced security policy management mechanisms	4	Security Policy Manager and 2 security enablers	3 additional security enablers	Security Policy Manager and 5 security enablers
WP7	Peer reviewed publications on application level security mechanisms	3	2 journal papers, and 1 PhD thesis	1 conference paper	1 conference & 2 journal papers, and 1 PhD thesis

Table 2.6 - Measurable indicators of Objective 6

The security architecture in the MiCADO framework is based around the Security Policy Manager that provides central management for security services (or security enablers). It follows the philosophy of pluggable architecture. As a result, the enablers can be easily integrated with the actual implementations of the MiCADO framework. The Security Policy Manager handles security enablers, such as Image Verifier to check container image, CryptoEngine to provide cryptographic functions, Credential Manager to provide authentication and authorization services to help hinder user impersonation attacks, Credential Store to store sensitive information and Zorp to provide firewall and TLS/SSL. These

security enablers are the key security services to implement the required security mechanisms in the MiCADO framework to make it a secure deployment and execution environment. The Security Policy Manager provides an aggregation of Restful API endpoints that serves different MiCADO master node components. It has been integrated with the MiCADO framework to deliver security-related features and operations. The security enablers are presented in deliverable D7.5 "MiCADO Security Modules Reference Implementation".

WP7 published 1 paper in conference proceedings on MiCADO security in M19-M33.

Objective 7: Maximising the impact of the piloted, demonstrated and validated market-ready offering by focused dissemination and marketing campaign targeting specifically SME and public sector use-cases beyond project partners.

COLA will specifically address commercial exploitation and sustainability of project results. Business models for commercial exploitation will be developed. Potential user communities, especially within SMEs and public sector organisations will be identified and targeted with dissemination and marketing activities. Multiplier organisations representing SME clusters and public sector domains will be utilised to reach large number of potential end-user organisations. Measurable indicators of Objective 7 are collected in Table 2.7.

Objective 7 indicators – COLA achieved by M33

WP	Measurable Indicator	targeted	M01-M18	M19-M33	M01-M33
WP3	Commercial exploitation plans and business models developed	5	0	exploitation plan and business model for MiCADO scale and for 14 COLA partners	15 exploitation plans and business models
WP2	Dissemination events to disseminate the MiCADO framework and its applicability within the SME and public sectors.	15	20	12	32
WP2	Multiplier organisations successfully disseminating the results of the COLA project.	12	9	6	15
WP2	Best practice cases studies for disseminating the utilisation of the MiCADO framework within SMEs and public sector organisations.	4	0	case studies of 3 COLA use cases + Data Avenue demonstrator	case studies o 3 COLA use cases + Data Avenue demonstrator
WP2	Press releases.	10	6	6	12
WP2	Specific training courses to train application developers to apply the MiCADO framework when developing cloud-aware applications.	2	2 code camps, 3 online tutorials	1 code camp, 2 on-line tutorials and 2 webinars	3 code camps, 5 on-line tutorials and 2 webinars

Table 2.7 -Measurable indicators of Objective 7

WP2 ran two types of dissemination activities. The first type are events that either WP2 organized, for example the Cloud Computing Experience Day in Germany, or CloudSME UG represented COLA, for example the COLA booth at the Hannover Messe in Germany. The second type included events that COLA partners attended, for example IWSG 2019. 12 COLA dissemination activities have taken place in M19-M33. Details of these events are available in deliverable D2.4 "Final dissemination report". COLA has established contacts with further 6 multiplier organizations: EOSC Hub, Amsterdam (agreed on publishing MiCADO framework on their market place, action is ongoing), EGI, Amsterdam (after signing a the first MoU, a new collaboration plan in preparation, ongoing), e-Shelter Innovation Lab, Frankfurt (NTT), contract signed on publishing MiCADO in their cloud innovation catalogue, action is ongoing), KI-map NRW (Innovation action for AI by the state NRW), partnership ECO/Euro Cloud, (largest Association of the Internet Industry in Europe), cloudSME is member in the association, dissemination partner and GfW Duisburg (local Economic Development), cooperation and support (Cloud Computing Symposium) in M19-M33.

WP2 published further 6 press releases in M19-M33. COLA has received media coverage in newspapers and (online) magazines in Germany, Spain and the UK – also with European visibility in M19-M33. WP5-WP7 ran the 3rd code camp in London in 28-30 January 2019 to train COLA Application Developers. In M19-M33 WP5-WP7 developed 2 on-line tutorials related to the MiCADO framework that explain how to use the MiCADO framework to deploy and run applications in the Cloud. Additionally, these work packages ran 2 on-line training courses as webinars on deployment and utilisation of the MiCADO framework, the descriptions of applications using the TOSCA-based Application Description Templates. Details of these dissemination activities are presented in deliverable D2.4 “Final dissemination report”.

WP3 developed two types of exploitation plans and business models: one for MiCADOscale and another for COLA project partners. The work package created 15 exploitation plans and the relevant business models.The exploitation plans and business models are described in D3.3 “Final Commercial Exploitation Plan and Sustainability Report”. WP2 and WP3 in cooperation with WP8 developed best practice case studies of the 3 COLA use cases and the Data Avenue demonstrator.

3. Explanation of the work carried per WP

In this section we outline activities, achievements and results of work packages and how they met the work package objectives in M19-M33.

3.1 WP1 Project Management

Work done in WP1

Task ID	Task Title	Start month	End month
T1.1	Establishing and running the project management structure	M01	M33
Partners	UoW		

UoW as the Project Coordinator led the project management activities. UoW managed the COLA mailing lists, to support efficient communication among project partners, and the COLA Pydio storage facility, to help information exchange among project partners. T1.1 coordinated all COLA activities through regular Skype and Webex meetings. The task also introduced a quality assurance process for all project deliverables where internal reviewers were assigned to every deliverable providing feedback and request for improvement towards the WP Leaders.

Task ID	Task Title	Start month	End month
T1.2	Monitoring the project progress	M01	M33
Partners	All partners		

T1.2 created two task forces to monitor progress in application support and technical development. Each task force had a Webex meeting every second week, organized by CloudSME UG, to monitor progress in research and technical development and implementation of COLA use cases. The Application Task Force (ATF), led by Jose Manuel Martin Rapun, Inycom coordinated activities related to the use case implementation. Use case owners and Independent Software Providers (ISV) attended these meetings. The Technical Task Force (TTF), led by Gabor Terstyanszky, UoW, involving WP4, WP5, WP6 and WP7 WP Leaders and researchers monitored progress in development tasks, discussed problems identified with prospective solutions and gave a short overview of further tasks. Project partners organized internal COLA project team meetings every week to present the latest progress, discuss technical problems arisen and create tasks list for the next week. They also collected short summaries and timesheets from all COLA researchers and produced monthly activity and effort usage reports. T1.2 compiled D1.4 “First Periodic Project Report” that described the administrative, financial and technical activities and achievements in M01-M18.
UoW initiated the extension of the COLA project by 3 months up to M33. We negotiated the extension request with the EU Project Officers and modified Part B of the Grant Agreement and project data on the Participant Portal (Part A). The extension request was accepted and the new end date of the project was set to M33.

Task ID	Task Title	Start month	End month
T1.3	Coordinating of the financial management of the project	M01	M33
Partners	All partners		

The COLA Financial Officer at the University of Westminster set up and ran the network of Financial Officers of the COLA project partners to manage finances of the project. UoW transferred the second instalment of the COLA budget to each COLA partner.
CloudSigma provided the required cloud resources for COLA. This has been tracked accurately and reported back to CloudSigma’s financial team. It must be emphasized that cloud resource consumption has exceeded the allocated resources agreed in the Grant Agreement.

Task ID	Task Title	Start month	End month
T1.4	Organizing project administrative meetings	M01	M33
Partners	UoW		

This task led the preparation for the first review meeting, held in Brussels on 19th September 2018. T1.4 also addressed the issues raised by the reviewers. The task organised two project meetings:

- 3^{3d} Cola Code Camp and Technical Meeting in London, UK on 28-30 January 2019
  - WP4-WP7 presented the MiCADO framework focusing on application description, application deployment and execution and security issues.
  - WP8 presented the COLA use cases. The project partners discussed how the COLA use cases can be described, deployed and executed on the Cloud using the MiCADO framework.
- 4th project meeting held in Corfu, Greece, on 18-19 June 2019.
  - It combined standalone and joint WP sessions, training sessions, live demonstration and a PMB meeting. The meeting discussed progress and finalized the roadmap of application and technical developments by M33.

Task ID	Task Title	Start month	End month

T1.5	Defining, implementing and monitoring the project's Data Management Plan	M01	M33
Partners	All partners		
COLA project partners monitored all activities that might affect DMP. Based on their inputs no changes were required in the COLA DMP. As a result, the DMP, presented in D1.3, was not modified.			
Task ID	**Task Title**	**Start month**	**End month**
T1.6	Communication with organizations and other projects	M01	M33
Partners	All partners		
T1.6 coordinated collaboration activities with other EU projects by participating in various clustering activities. COLA contributed to the work of two clusters: Cluster of Cloud-oriented projects (including DECIDE, CLOUDPERFECT, ACTiCLOUD, MELODIC, RESTASSURED and COLA) and the SE4SA (Software Engineering for Trustworthy Services and Applications) cluster (including Aligned, AppHub, ARCADIA, ARTIST, CloudTeams, CloudWave, COLA, DECENTER, DECIDE, DICE, DITAS, ElasTest, ENTICE, Envisage, HyVar, MATILDA, MELODIC, MODAClouds, MONDO, OpenReq, Prowess, Q-Rapids, RISCOSS, SeaClouds, S-CASE, STAMP, Supersede, SWITCH, TANGO, U-QASAR). COLA contributed to two networking sessions organised by these clusters during the ICT 2018 event in Vienna. COLA also established contacts with FORD MOTOR COMPANY and the Singapore simulation community. Further, T1.6 started communication with OASIS (Organization for the Advancement of Structured Information Standards) in order to support the participation of COLA researchers in OASIS activities.			

WP1 objectives and relevant achievements

Task 1.1 - Objective 1.1 Create and run the project management structure including administrative and financial aspects of the project.
• efficient administrative and technical project management based on the COLA project management structure using the COLA mailing lists that provided efficient and reliable communication channels among project partners and the COLA Pydio repository that offered 24/7 access to all project documents;
Task 1.2 - Objective 1.2 Monitor the project overall progress and check resource usage considering the Grant Agreement and handle any problem or risk identified.
• D1.4 First Periodic Project Report has been submitted and accepted with request for some minor modifications; • 1st review meeting accepted all submitted deliverables including D1.4 First Periodic Project Report, confirmed that all milestones in M01-M18 were achieved and evaluated the project progress as "the project has fully achieved its objectives and milestones for the reporting period"; • COLA met all aims and objectives of M19-M33 according to the Grant Agreement outlined in MS5 (or MS1.5) "Indicators and objectives achieved, deadlines met, and project budget spent as planned overall"; • All deliverables have been submitted on time or with some minor delays;
Task 1.3 - Objective 1.3 Coordinate and organize administrative and financial reporting and submit reports to EC.
• EC accepted the financial report submitted with the First Periodic Report; • efficient financial management of the COLA project including transfer of the second instalment to all COLA partners;
Task 1.4 - Objective 1.4 Organize and run project administrative meetings and review meetings.
• successful Project Review Meeting held in Brussels on 19/09/18; • two project meetings contributed to progress of development of the MiCADO framework and implementing COLA use cases (3rd code camp and technical meeting and 4th project meeting);
Task 1.5 - Objective 1.5 To drive and significantly contribute to the standardisation of cloud orchestration at application level.Define, implement and monitor the project's Data Management Plan.
• DMP, presented in D1.3, still stands as it was since no requirements were identified that needed changes;
Task 1.6 - Objective 1.6 Communicate the project vision at European and international events, and establish and keep contacts with national and international organizations and projects.
• successful contribution to the work of two EC projects clusters.

Deviations from the Grant Agreement (Annex I + Annex II) in WP1

UoW as Project Coordinator requested a three month-long extension to manage deviations caused by the two partner changes. It was accepted and a 3 months extension was granted.

3.2 WP2 Dissemination, communication, training and standardisation

Work done in WP2

Task ID	Task Title	Start month	End month
T2.2	General dissemination activities	M01	M33
Partners	All partners		

Dissemination materials such as printed brochures / flyers were designed, printed and distributed. In addition, roll-up banners and posters were designed and produced to be used at exhibitions and trade fairs. Partners have been supported by providing press releases to reuse and printed brochures. New website (MICADOscale) and new MiCADO related social channels have been planned, designed and created. News about the project has been disseminated over all those channels. A MiCADO brochure (A5, 6p) has been released for public information. Further, CloudSME organized 2 MiCADO related dissemination events:

- Cloud, Edge, and Fog Computing – Duisburg, 13/04/2018
- Cloud Computing Symposium 2019 – Duisburg, 20/09/2019

WP2 reported COLA dissemination activities in deliverable D2.4 “Final dissemination report”.

Task ID	Task Title	Start month	End month
T2.3	Organising training events	M04	M33
Partners	SZTAKI, CloudSME, UoW, SICS, CB, ST, CS		

UoW and SZTAKI developed and ran 2 webinars (on-line training events) to promote and provide training related to the MiCADO framework. Both Webinars targeted both internal and external; audiences:

- Application Description Template webinar - Building TOSCA Application Description Templates for MiCADO and
- MiCADO webinar - How to automate Deployment and Orchestration of Application Cluster.

MiCADO installation and user guide have been set up by SZTAKI on readthedocs.org and have been updated with each new version of MiCADO. Also a set of tutorials presenting the COLA use cases has been created on readthedocs.org to support the adaption and usage of the MiCADO framework. UoW created several on-line tutorials:

- tutorial to explain how to create ADTs to support application developers;
- tutorial to demonstrate the newly integrated web authentication, as well as application examples of consumption-based scaling and deadline-based scaling using MiCADO v0.6.0;
- set of video tutorials, developed together with CloudSME, to explain ADT development, deployment of the MiCADO Master node and running all included test demonstrator applications and
- tutorial to present how JaamSim can be orchestrated using jQueuer on the MiCADO platform.

T2.3 described the COLA training events in deliverable D2.4 “Final dissemination report”.

Task ID	Task Title.	Start month	End month
T2.4	Collecting community feedback	M13	M33
Partners	All partners		

T2.4 led the community feedback process. The task organized teleconferences involving COLA project partners to manage community feedback. T2.4 ran a community feedback survey that was split into 2 sub surveys (technical and non-technical). To collect this feedback CloudSME in collaboration with SZTAKI and UoW elaborated a web questionnaire based on MiCADO version 0.6.1. T2.4 reported the community feedback in deliverable D2.3 “User community feedback”. The task forwarded the survey to both technology developers and use case owners to be able to consider the survey’s outputs in the development of the MiCADO framework and in the implementation of COLA use cases.

Task ID	Task Title	Start month	End month
T2.5	Contribution to standardisation	M01	M33
Partners	UoW, SZTAKI, SICS, CS, UBRUN, CloudSME		

UoW coordinated standardisation related activities. There were two major types of activities. First, technical work packages investigated existing standards and selected those ones needed in the design and implementation of the MiCADO framework and setting up and running the COLA production and testbed infrastructure. These standards have been used in the MiCADO framework and in these two infrastructures. Deliverable D2.5 “Report on standardisation activities” described these standards and how they are used in COLA. Second, WP5 and WP7 approached OASIS TOSCA working group and IETF Trusted Execution Environment Provisioning (TEEP) working group, respectively. Both WP5 and WP7 made the first steps to contribute to standardisation activities of these working groups.

WP2 objectives and relevant achievements

Task 2.2 - Objective 2.2 To disseminate and promote the project's achievements among SMEs and public sector organisations, and the general public
• over 75.000 impressions generated (web & social channels); • 6 press releases distributed in English, German and Spanish; • participation in 12 dissemination events; • 11 conference and journal papers are published; • 2 COLA conferences organized: ▪ Cloud, Edge, and Fog Computing – Duisburg, 13.04.2018 ▪ Cloud Computing Symposium 2019 – Duisburg, 20.09.2019 • active participation and exhibition in major Trade Fairs (HMI 2017/2018/2019); • successful business oriented image – MiCADOscale ->to reach out companies and public organisations that would be prospective MiCADO users; • commercial market traction raised significantly by the end of the project, shown by interest and uptake of some early multipliers (EOSC-hub, EGI) and first commercial adaptors (HKN/Nextcloud); • deliverable D2.4 "Final dissemination report" presented COLA dissemination events;
Task 2.3 - Objective 2.3 To organise training events for application developers to get them familiar with the MiCADO framework to develop cloud-aware applications.
• complete user guide with use case tutorials on readthedocs.org available; • 2 on-line tutorials created, available on YouTube channel (MiCADO by COLA project); • Slideshare channel with 12 presentations; • 2 MiCADO webinars: "How to create Application Description Templates" and "How to automate Deployment"; • deliverable D2.4 "Final dissemination report" presented COLA training events;
Task 2.4 - Objective 2.4 To collect community feedback from SMEs and public sector organisations about the quality and applicability of the MiCADO framework and the COLA project results
• community survey conducted and evaluated MiCADO v0.6.1 and reported in deliverable D2.3 "User community feedback";
Task 2.5 - Objective 2.5 To drive and significantly contribute to the standardisation of cloud orchestration at application level.
• MiCADO framework is built on existing standards, such as OASIS TOSCA to describe applications, • T2.5 established contact with the OASIS TOSCA and IETF Trusted Execution Environment Provisioning (TEEP) Working Group; and WP5 and WP7 started cooperation with these working groups; • deliverable D2.5 "Report on standardisation activities" presented how COLA used standards and COLA efforts on standardisation;

Deviations from the Grant Agreement (Annex I + Annex II) in WP2
Submission deadline of deliverable D2.4 "Final dissemination report" and D2.5 "Report on standardisation activities" were rescheduled due to the project extension.

3.3 WP3 Commercial exploitation and sustainability

Work done in WP3

Task ID	Task Title	Start month	End month
T3.1	Validating economic feasibility of the COLA use-cases	M01	M33
Partners	CB, Outlandish, Inycon, Saker, CloudSME UG, Sarga, Now, UBRUN		
WP3 continued analysing economic feasibility of the COLA use-cases. CB led this task cooperating with all other technology providers and user use case owners. T3.1 collected and analysed business models of COLA project partners and the economic outputs of the use cases were discussed at project meetings. Economic feasibility and business model of use cases were taken into consideration for running the marketing campaign. Further, T3.1 analysed sustainability and feasibility of pre-commercial use cases to prove economic feasibility of the project outcomes (i.e. collaboration of MiCADOscale with HKN GmbH with the Nextcloud application). Based on this analysis, CloudBroker and CloudSME conducted financial planning of further pre-commercial and commercial usage of MiCADOscale services by existing and potential stakeholders.			
Task ID	**Task Title**	**Start month**	**End month**

T3.2	Commercial exploitation, IPR management and sustainability of the SME use cases, the public sector solutions, and the MiCADO architecture and its reference implementation	M01	M33
Partners	CB, UOW, SZTAKI, SICS, CS, BalaSys, INYCOM, SARGA, NOW, UBRUN, SAKER, OUTLANDISH, cloudSME		
In order to analyse commercial exploitation, sustainability and IPR management, T3.2 elaborated questionnaires to collect information on commercial exploitation and sustainability plan and IPR management of project partners. This task collected and analysed COLA use case owner partners' exploitation and sustainability plans, and management strategy of IPs created inside or outside of COLA. T3.2 also defined the MiCADOscale business model and value proposition by the end of the project. The task used the Business Model Canvas as well as the Value Proposition Canvas to develop this business model. The results of this task are presented in detail in D3.3 "Final commercial exploitation and sustainability report" deliverable.			
Task ID	**Task Title**	**Start month**	**End month**
T3.3	Marketing campaign to commercialise and sustain project results M01-M30	M01	M33
Partners	CB, UOW, SZTAKI, SICS, CS, BalaSys, INYCOM, SARGA, NOW, UBRUN, SAKER, OUTLANDISH, cloudSME		
T3.3 planned and successfully conducted an integrated marketing campaign. Details and results of this marketing campaign were provided in deliverable D3.2 "Marketing campaign to support sustainability and commercialization".			

WP3 objectives and relevant achievements

Task 3.1 -

- information for monitoring economic impact of the COLA use cases was collected from use case owner partners, related materials (e.g. questionnaires) were improved, collected information was analysed, processed and discussed at the project meetings;
- business models of COLA use cases were collected, discussed and refined;
- validation of economic feasibility by applying the developed MiCADO framework within CloudSME with external users has been done;
- first commercial use case has been planned and started: "MiCADOscale managed Nextcloud" (HKN data center acting as the distributor of professional Nextcloud/MiCADOscale services);
- initial testing of MiCADO by HKN has been completed, financial planning of this use case has been completed;

Task 3.2 Objective 3.1 To contribute to the commercial exploitation and sustainability of products and services developed in the COLA project within the SME sector

- MiCADO business model and value proposition was defined, and adjusted as the project evolved;
- business model and value proposition of MiCADO was upgraded to support commercialisation of the project outcomes;
- competitor analysis of MICADO in the SME sector was completed and regularly upgraded in accordance with evolution of the MiCADO framework;
- strategy for MiCADO support and development for MiCADOscale) after the end of the COLA project was defined;

Task 3.2 Objective 3.2 To contribute to the commercial exploitation and sustainability of products and services developed in the COLA project within public sector organisations.

- MiCADO business model and value proposition was defined, and adjusted as the project evolved;
- business model and value proposition of MiCADO was upgraded to support commercialisation of the project outcomes;
- competitor analysis of MICADO in the public sector was completed and regularly upgraded in accordance with evolution of the MiCADO framework;
- strategy for MiCADO support and development for MiCADOcommunity at the end of the COLA project was defined;

Task 3.2 - Objective 3.3 To contribute to the commercial exploitation and sustainability of the MiCADO platform as major output of the COLA project.

- exploitation and sustainability metrics were collected from the project partners using questionnaires, along with their plans for commercialisation and further usage of the project outcome;
- IPR information was collected from the partners, key IRP issues were discussed at the meetings, main COLA IPs were defined;

- MiCADO sustainability plans were made, the most important potential customers were identified, communication with them was setup so that they are informed about new MiCADO releases;

Task 3.3 - Objective 3.4 To develop and execute an integrated marketing campaign in support of the successful commercialisation of the project.

- marketing merchandise (T-shirts, pins) and print materials (leaflet, roll-up, brochure) were planned, approved, created and distributed to potential MiCADO users;
- KPIs for marketing actions were tracked and analysed, the most effective marketing actions were identified, necessary adjustments to the marketing campaign were made;
- COLA marketing campaign to promote the MiCADO framework was planned and successfully conducted through digital marketing activities and channels;
- promotion of MiCADO at different events (CloudFest, Hannover Messe, Tech Week Frankfurt, etc.) significantly contributed to increasing MICADO brand awareness and increased the number of potential customers of MiCADO;
- binary marketing approach was introduced dividing MiCADO brand into two sub-brands: MiCADOcommunity, the open source version, and MiCADOscale, the community version
- marketing campaign was adjusted and aligned with this approach: customer segmentation, product positioning and distribution, etc.;
- market and technology readiness assessments of the project outcomes were completed, recommendations were received, analysed and followed;
- financial planning for to the commercial project "MiCADOscale managed Nextcloud" was completed;
- marketing activities (webinar sessions, blog campaign, personal meetings, presentation of project outcome at events etc.) after the COLA project were planned and approved by the project consortium;

Deviations from the Grant Agreement (Annex I + Annex II) in WP3

Submission deadline of deliverable D3.2 "Marketing campaign to support sustainability and commercialization" and D3.3 "Final commercial exploitation and sustainability report" were rescheduled due to the project extension.

3.4 WP4 Cloud Access Layer and Testbed Infrastructure

Work done in WP4

Task ID	Task Title	Start month	End month
T4.2	Deployment, operation and support of development testbed infrastructure	M01	M33
Partners	CS, UoW, SZTAKI, SICS, CB, ST		

WP4 continued providing the COLA development testbed infrastructure. The testbed includes academic and commercial clouds. CloudSigma's commercial proprietary stack is available for project partners via either the CloudBroker platform or directly. RISE's and UoW's OpenStack-based cloud and SZTAKI's OpenNebula-based cloud were used extensively for the development of the MiCADO framework (WP5-WP7) and of COLA use cases (WP8). T4.2 provided technical support for these academic clouds and for the integration of the Microsoft Azure cloud to the testbed infrastructure. The CloudBroker Platform acted as a bridge between the MiCADO framework and the testbed in accordance with the project requirements. WP6 and WP7 used the testbed infrastructure to check compliance of the MiCADO framework with both OpenStack and OpenNebula before every MiCADO release.

Task ID	Task Title	Start month	End month
T4.3	Deployment, operation and support of production infrastructure	M01	M33
Partners	CS, UoW, SZTAKI, SICS, CB, ST		

T4.3 set up and managed a production test cloud infrastructure to simulate deployment and execution of applications in a commercial production context. This infrastructure contains cloud resources of CloudSigma, RISE and UoW. For example UoW's cloud was used to run and benchmark some of the proof of concepts demonstrators, such as Repast and JaamSim. To support this infrastructure the task developed a pseudo cloud-init script to be included in the sysprep of Windows images, which was hosted in GitLab.

ScaleTools migrated of the CloudBroker Platform to Rails 5 and provided support for the maintenance activities that followed. T4.3 verified that all functionalities and access to support cloud providers works properly. The task integrated the MiCADO framework with the CloudBroker Platform, and made available it as a core feature within the Infrastructure Visual Screen (IVS). This allows running applications that should be scaled by MiCADO in the Cloud through the CloudBroker Platform. The task created ADTs that are partially automated with the IVS inputs. T4.3 created a solution that defines the desired infrastructure from the given ICS data and automatically deploys the

MiCADOscale Master-node. Based on this development the ADT documentation was upgraded providing more detailed information on component creation and usage in a multi-cloud environment.
To support near production or production deployment and execution of COLA use cases T4.3 also provided access to commercial production cloud infrastructures through CloudBroker Platform.

Task ID	Task Title	Start month	End month
T4.4	Microservices performance benchmarking	M01	M33
Partners	CS, UoW, SZTAKI, SICS		

T4.4 set up a Jenkins test environment and configured it for the project. Several methodologies were investigated to execute MiCADO services within this automated environment. T4.4. performed general maintenance of the benchmarking environment in M19-M33, added additional plugins needed for the set up, and provided ongoing support the project partners. The benchmarking led to improving the CloudBroker Platform, testing the MiCADO Optimizer and checking performance of COLA use cases. Some project partners were experiencing performance anomalies with CloudSigma's production cloud accessing it via the CloudBroker Platform. T4.4. ran additional troubleshooting and performance testing to understand where performance bottlenecks originated. CloudSigma investigated how the CloudBroker Platform was provisioning guests and their core frequency and the problem was resolved. The task also improved and upgraded the infrastructure layer according to the feedback received from project partners. WP6 ran intensive testing of the MiCADO Optimizer. The work package has set up and investigated several configurations of the Optimizer and performed detailed measurements of a sample application working with optimizer-based scaling method.

Task ID	Task Title	Start month	End month
T4.5	Implementation of enhancements of the cloud access layer	M01	M33
Partners	CS, CB		

T4.5 significantly improved the CloudBroker Platform. CloudBroker and Scaletools designed and developed the Infrastructure Visual Screen (IVS). The task elaborated a Configuration Advisor as a new functionality of the CloudBroker Platform. It offers an advisory mechanism to allow user specifying generic requirements. Having these requirements the CloudBroker Platform suggests several resource-region-instance type configurations that suit the query best. T4.5 developed a Resource Catalogue functionality for the CloudBroker Platform to simplify the process of resource selection. All cloud resources available through the CloudBroker Platform were compiled in a joint that allowed developing an additional functionality for the platform. T4.5 made CloudBroker App Centre technologies available for COLA use cases. The cloud access mechanism of the App Centre was updated. Security enhancements of the CloudBroker Platform were also completed including increased data safety and establishing an effective backup procedure for the COLA server.

WP4 objectives and relevant achievements

Task 4.2 - Objective 4.2 To create a production and a testbed cloud infrastructure consisting of commercial and academic cloud resources based on the requirements of the microservices.

- development testbed infrastructure has been provided by CloudSigma and UoW, SZTAKI and RISE;
- CloudSigma accounts have been created and managed to provide access developers and end users to cloud resources;
- Microsoft Azure cloud has been integrated to the production and testbed infrastructure;
- Resource Catalogue and Configuration Advisor developed to simplify the selection of cloud resources;
- changes in the Data Files Layer of the CloudBroker Platform let the files to be transferred directly from/to SFTP server;
- new technologies are employed in the CloudBroker Platform to deliver better performance and security;
- CloudSigma's commercial services were improved based on COLA partners' enhancement requests and issues reported;
- deliverable D4.3 "Updated COLA development testbed and production infrastructure" submitted;

Task 4.3 - Objective 4.3 To investigate optimal container size and infrastructure requirements of microservices

- functionality of the CloudBroker Platform has been improved and optimizations to the cloud infrastructure have been made when necessary;
- Infrastructure Visual Screen (IVS) on the CloudBroker Platform allows users to launch a graphically composed infrastructure of nodes via MiCADO;
- IVS supports the advanced scaling mechanisms of the MiCADO framework;
- Docker image(s) to be launched on the node can be specified;
- policies regarding average CPU and RAM usage and set the min/max bounds on each node can be defined;

Task 4.4 - Objective 4.4 To assess infrastructure performance for optimisation of cloud applications
• developers and end users were able to run performance testing on regular basis; • all user feedbacks have been considered and acted upon to ensure optimal performance and relevant upgrades and improvements have been made to the cloud infrastructure;
Task 4.5 - Objective 4.5 To enhance the cloud access layer based on the requirements of the COLA use-cases as well as from the upper and lower layers
• user feedback has been addressed with multiple updates and improvements on to the CloudBroker Platform and the interfaces with the various cloud infrastructure;

Deviations from the Grant Agreement (Annex I + Annex II) in WP4

Submission deadline of deliverable D4.3 "Updated COLA development testbed and production infrastructure" and deliverable D4.4 "Upgraded CloudBroker Platform" was rescheduled due to the project extension.

3.5 WP5 Application definition templates

Work done in WP5

Task ID	Task Title	Start month	End month
T5.4	Specification and publication of templates and service descriptions	M09	M33
Partners	UoW, SZTAKI, CB, ST, SICS		

T5.4 has continued to cooperate with WP4-WP8 to continuously update and expand the Application Description Templates (ADT) and to structure and populate a repository of Application Description Templates. These activities required a close cooperation with WP4 to ensure the compatibility with the Cloud execution layer, with WP6 to ensure that the ADTs can express the full range of information (application topology and policies) needed by the MiCADO framework, with WP7 to ensure that the ADTs are compatible with the security policies of the framework, and, finally, with WP8 to ensure that the ADTs are capable to describe the desired behaviour of application as specified by the end users.

T5.4 refined the existing set of the ADTs and demonstrated how to write and deploy applications using ADTs during the 3^{3d} Cola Code Camp and Technical Meeting. The task has implemented TOSCA-based abstractions to deal with different orchestration components. This approach was successful in supporting the change from Docker Swarm to Kubernetes as container orchestration technology with only minor effort and changes. To enhance usability and user-friendliness, T5.4 has created examples, called skeletons, to help users build ADTs from scratch; such skeletons consist of sections of previously defined ADTs that could be reused with slight modifications. Usability and user-friendliness wass further enhanced by the definition of sets of variables that can be set through an input section without requiring any editing in the code itself. This allows developers that are not TOSCA experts to select a compatible ADT and only define input variables prior to submission. WP5 and WP6 cooperated to allow the definition of instance contextualisation (cloud-init) in-line in an ADT to allow extra commands to be appended. This enables users to fully overwrite the cloud-init which adds context to a cloud instance. T5.4 added properties to describe a Kubernetes Workload that could be split into two sections: workload specific and pod specific. Finally, the task has modified the ADT to support both the Kubernetes and Docker naming conventions. T5.4 cooperating with WP4 added an "infrastructure_component_id" property for CloudBroker nodes which was required for integration with the CloudBroker "infrastructure screen", and "hv_relaxed" and "hv_tsc" properties in CloudSigma node definitions to allow fine tuning of Windows VM Machines.

WP5 organized discussions with WP4-WP8 during the 4th project meeting. These discussions aimed at ensuring the expressivity and user friendliness of the ADTs. Based on these discussions T5.4 and WP6 added support for the "availability zone" property for OpenStack nodes. The task has also improved metadata, order and comments within the main TOSCA types file that compose ADTs. Further, WP5 and WP7 extended support for the Kubernetes Secrets policy for sensitive data sharing in applications and for the L7 Firewall policies, giving users the ability to define port rules for an application level firewall. WP5 responded to WP8 feedback that ADTs were too complex by adding abstraction layers to move complexity away from some complex elements of TOSCA such as artefacts and interfaces, and set defaults for common settings. Finally, following feedback from WP6 and WP8, WP5 added monitoring types to MiCADO to give users the ability to choose which metric collectors to enable for a specific application deployment.

WP5 objectives and relevant achievements

Task 5.4 - Objective 5.4 To set-up a repository for storing, publishing and searching application templates and their artefacts.

- ADT repository established on github (https://github.com/micado-scale/tosca);
- ADT repository populated with updated ADTs for 3 COLA use cases and 24 COLA proof of concept demonstrators;
- ADT repository populated with ADT code snippets, skeletons and examples to help developers to learn how to adapt existing ADTs or write new ones;

Task 5.4 - Objective 5.5 To specify and publish descriptions of basic services and their implementations needed in different public sector and SME use-cases

- flexible and adaptable structure to describe both the application components (topology) and behaviour (policies) has been developed and constantly updated to satisfy the requirements of WP4-WP8;
- 3 COLA use cases have been successfully described and tested;
- 24 prototypes have been successfully described using Application Description Templates;
- deliverable D5.5 has been submitted with one month delay.

Deviations from the Grant Agreement (Annex I + Annex II) in WP5

Deliverable D5.5 "Second Set of Templates and Services of Use Cases" has been submitted late because of on-going developments of the Application Description Templates and creating ADT for 24 COLA demonstrators.

3.6 WP6 Microservices deployment and execution layer

Work done in WP6

Task ID	Task Title	Start month	End month
T6.4	Development of the price/performance optimization extension of the Scalability Decision Maker microservice	M16	M33
Partners	SZTAKI, UoW, ST		

WP6 worked on a price/performance optimization extension of the Scalability Decision Maker (Policy Keeper) microservice. For this purpose, the **MiCADO Optimizer** component/service has been developed which performs periodic calculation in the background and generates advices for scaling. The work started with intensive research in relation to optimization techniques. Identification of the machine learning optimization techniques and methods were followed by design of the operation, architecture and integration. Optimizer has been developed, intensively tested and validated. Finally, it was integrated into MiCADO and released in version 0.8.0. A demo application (wordpress) with special Optimizer-based scaling rule was developed and used for testing the Optimizer for training and scaling.

Beyond the Optimizer, WP6 further developed the MiCADO framework in several aspects. All these developments have been summarised and detailed in deliverable D6.4. **MiCADO Policy Keeper.** WP6 further developed and upgraded Policy Keeper in this period with new features improving monitoring, scaling and logging. A journal paper has been also published in Journal of Grid Computing describing Policy Keeper and its integration with MiCADO entitled "Supporting programmable autoscaling rules for containers and virtual machines on clouds". During the period, Policy Keeper has been integrated with Kubernetes as well as with the Optimizer service. **Occopus.** During the period bugfixing and features like tagging ec2 resources, supporting keystone V3 for Openstack and downscale by ip address have been developed to enhance Occopus as needed by MiCADO users. **MiCADO Submitter**. WP6 developed the MiCADO Submitter, first released in MiCADO v0.5.0, to process and deploy the application - described by Application Description Templates - to the Cloud. WP6 extended the MiCADO Submitter to support enhanced querying features of the API, to support VM-only deployments (evacuation use case), to support the latest TOSCA specification – v1.2. A generic translator was developed for generating a TOSCA ADT based on details from proprietary configuration files and integrate it with JQueuer for JSON to TOSCA translations. The Kubernetes Adaptor was re-factored to prepare it for extended support of Kubernetes resources in future MiCADO versions.

JQueuer. The JQueuer job submission framework has been developed and documented. JQueuer, as an external component to MiCADO enables the submission of a large number of container based jobs and therefore indirectly supports the scalable execution of such applications for a set deadline. JQueuer was added to MiCADO v0.7.0 release. JQueuer was modified to run as application in MiCADO, rather than as an entirely external service. Additionally, WP6 (in collaboration with Brunel University) successfully published a journal paper in Future Genetation Computer Systems describing JQueuer and its integration with MiCADO titled "A Cloud-agnostic Queuing System to Support the Implementation of Deadline-based Application Execution Policies"

MiCADO. 9 MiCADO versions have been released in the reporting period: v0.5.0 (12 July 2018), v0.6.0 (10 Sept 2018), v0.6.1 (15 Oct 2018), v0.7.0 (12 Dec 2018), v0.7.1 (10 Jan 2019), v0.7.2 (25 Feb 2019), v0.7.2-rev1 (01 Apr 2019), v0.7.3 (14 Jun 2019), v0.8.0 (30 September 2019). Kubernetes was integrated into MiCADO as an alternative container orchestrator to Docker Swarm from MiCADO v0.7.0. Later, WP6 launched MiCADO v0.7.1 improving support for the Kubernetes based container orchestrator and MiCADO v0.7.2 with a native Kubernetes adaptor inside the MiCADO Submitter. WP6 further developed MiCADO with a full-fledged Kubernetes based cloud orchestrator

and added support for building un-initialised MiCADO images to shorten MiCADO deployment time and improve the user experience and support for managing independent sets of virtual machines in a single MiCADO deployment. In MiCADO v0.7.3 release the MiCADO core components have been moved into Kubernetes Pods. Furthermore, WP6 started to develop a Terraform Adaptor for the MiCADO Submitter to support more cloud APIs e.g. Microsoft Azure. MiCADO v0.8.0 was the first release including the Optimizer component and service. During the period, development, release, documentation and communication related tools (e.g. github, docker hub, readthedocs, slack, etc.) were maintained to support the work of the developers. Documentation site at readthedocs (https://micado-scale.readthedocs.io) contains all the features of MiCADO releases during the period.

CloudBroker Platform integration. WP6 has worked on integrating MiCADO into the CloudBroker platform in a way that the users can launch MiCADO using the graphical environment of CBP including a newly designed infrastructure editor.

WP6 objectives and relevant achievements

Task 6.4 - Objective 6.4 To develop the price/performance optimization extension to the scalability decision service by which MiCADO can optimize the execution of running applications both from the point of view of performance and execution price according to QoS parameters provided by the application developer or end-user.

- first prototype of the MiCADO Optimizer has been developed and integrated with the MiCADO framework;
- 9 MiCADO releases in M19-M33 with many features listed on the documentation site at https://micado-scale.readthedocs.io/en/latest/release_notes.html;
- demonstrating modularity of the MiCADO framework with different cloud orchestrators (Occopus and Terraform) and container orchestrators (Docker Swarm and Kubernetes);
- supporting job submission for MiCADO by developing JQueuer as MiCADO application;
- supporting MiCADO from the graphical environment of the CloudBroker Platform;

Deviations from the Grant Agreement (Annex I + Annex II) in WP6

Submission deadline of deliverable D6.4 “Prototype and documentation of the price/performance optimization service” was rescheduled due to the project extension.

3.7 WP7 Security, privacy and trust at the level of cloud applications

Work done in WP7

Task ID	Task Title	Start month	End month
T7.5	Design and implementations of security modules	M16	M33
Partners	UoW, RISE, BalaSys, SZTAKI		

COLA use case owners identified their security requirements to deploy and run their applications in the Cloud. WP6 also forwarded the security requirements of the MiCADO framework. Considering these requirements T7.5 implemented security enablers:

- to verify OS images that are running the application containers;
- to handle and distribute application-related secret handling;
- to encrypt, authenticate and authorize web access to the MiCADO master node;
- to store cloud credentials in an encrypted way;
- to manage application-level firewalling for MiCADO applications and
- to secure communication between MiCADO master and worker nodes.

T7.5 developed the **Security Policy Manager** as the key security service. It is the single of point of access for MiCADO security services. It provides an aggregation of Restful API endpoints that serves different MiCADO master node components. It also acts as a workflow director that uses other security enablers to implement security-related business processes. T7.5 developed 5 security enablers: Image Verifier, Crypto Engine, Credential Manager, Credential Store and "Layer 7" firewall. The security enablers follow the philosophy of pluggable architecture. As a result, the enablers can be easily integrated with the actual implementations of the MiCADO services. The **Image Verifier** provides integrity security guarantees to the MiCADO framework verifying the integrity of application images prior to deployment. It also detects corrupted images prior to their instantiation in the cloud. The Image Verifier is implemented as an SGX library called libiivr. The **Crypto Engine** generates cryptographic algorithms and data to enforce the security of the communication between the services of the MiCADO framework. The **Credential Manager** provides user verification for Zorp enabling it to perform authentication and control access T7.5 selected the Flask-User Open source solution as the user management API to enhance the Credential Manager. Using Flask-User made the design more robust and new features such as dynamic role management, email notification, liaise with restful standards, password

management were added. The **Credential Store** is an infrastructure secret storage based on the open source Hashicorp Vault. T7.5 set up **"Layer 7" firewall**, using Zorp, is an application level firewall to protect the components on the master node by inspecting their actual communication on protocol level. It enforces protocol compliance and acts as a user authentication and authorization point for accessing the components on the master node. All external network connections are terminated on the firewall and recreated towards the internal components, effectively proxying the protocol traffic. T7.5 gave description of the implemented security enablers in deliverable D7.5: "MiCADO Security Modules Reference Implementation".

Task ID	Task Title	Start month	End month
T7.6	Security architecture evaluation	M25	M30
Partners	UoW, RISE, BalaSys		

The MiCADO security services were evaluated against the requirements collected from the COLA use cases, as well as the guidelines in Security and Privacy Controls for Information Systems and Organizations document published by National Institute of Standards and Technology (NIST). T7.6 elaborated guidelines for configuring supported security features in the MiCADO framework. The task ran hands-on penetration test on the MiCADO framework to identify any potential problems that have not been identified in the design phase and to prove the correctness of the deployed security services. T7.6 compiled deliverable D7.6 "Security Architecture Evaluation" presenting:

- evaluation of security requirements based on COLA use cases;
- evaluation of COLA security framework based on standards and
- evaluation of MiCADO framework based on NIST 800-53 standards.

WP7 objectives and relevant achievements

Task 7.5 - Objective 7.5 To develop, integrate and evaluate the key security modules of the security architecture of the MiCADO framework.

- detailed definition of the security enabler design;
- preparation of the test and development environment for development of the security enablers;
- credential distribution mechanism introduced in Occopus;
- Image Verifier has been containerized and integrated into the MiCADO framework;
- Crypto Engine has been containerized and integrated into the MiCADO framework;
- Security Policy Manager been developed, containerized and integrated into the MiCADO framework;
- Credential Manager and Credential Store have been developed, released and integrated into the MiCADO framework;
- Master Node L7 Firewall component has been developed, containerized with the MiCADO framework;
- IPSEC component has been developed and integrated with the MiCADO framework;
- FWaaS component has been developed, containerized and integrated with MiCADO framework;
- Application Secret Handling component has been developed and integrated with MiCADO framework;
- successful integration of the security enablers into the MiCADO framework and
- deliverable D7.5: "MiCADO Security Modules Reference Implementation" has and submitted;

Task 7.5 - Objective 7.5 To develop, integrate and evaluate the key security modules of the security architecture of the MiCADO framework.

- automated testing has been put in place;
- penetration testing of security enablers performed by BalaSys, an industrial project partner;
- evaluation of the security architecture and its implementation according to industry frameworks and standards;
- deliverable D7.6 "Security Architecture Evaluation" has been submitted;

Deviations from the Grant Agreement (Annex I + Annex II) in WP7

Submission deadline of deliverable D7.5 "MiCADO Security Modules Reference Implementation" and D7.6 "Security Architecture Evaluation" were rescheduled due to the project extension.

3.8 WP8 SME and public sector use-case pilots and demonstrators

Work done in WP8

Task ID	Task Title	Start month	End month
T8.3	Development of near to operational level pilots and demonstrators	M13	M33
Partners	Inycom, UBRUN, Sarga, Saker, The Audience Agency, Outlandish, ST, CB, UoW, SZTAKI		

T8.3 developed near to operational level demonstrators of the three COLA use cases. The task revised requirements for each use case both from the end-user's (usability, performance) and also from the software provider's (business model and operations, performance) points of view considering use case implementations created in T8.2. The demonstrators have been migrated to versions of the MiCADO framework improving their capabilities regarding dynamic scalability and security. Finally, end users and software vendors of each demonstrator have assessed the deployment and execution of these use case applications on the MiCADO framework from cost/performance, development, and usability points of view to provide feedback to the framework developers. Details of use case developments are given below:

- **use case 1: audience finder application** (Outlandish + The Audience Agency);
  - refined standard Docker templates for Outlandish projects and for the Audience Finder application using multi-stage docker build approach to reduce build time and image size;
  - Docker images build and published to Docker Hub using Automated builds;
  - created Docker Image for NGINX web server with integrated VTS plugin to produce comprehensive metrics on web traffic for Prometheus;
  - testing, refinement and improvement of Outlandish bespoke WordPress starter kit, consistently being used in multiple projects with out of the box docker support - with built in Gitlab CI pipelines to deploy project to MICADO instance;
  - investigated the use of ADTs to support the same ADT in multiple environments and projects with the minimum of work and the use of Ansible to deploy application to MICADO instances and integration with templating experiments to improve workflow of deploying to MICADO;
  - developed Ansible scripts to produce AMIs (machine images) for AWS that have the MiCADO software pre-installed on them;
  - produced PHP-FPM images that have integrated Prometheus exporters in them to produce metrics on PHP-FPM to a Prometheus instance;
  - recorded the change in NGINX and PHP-FPM metrics for the Audience Finder application and simple WordPress applications as they are placed under load to replicate the performance of these websites when visited by many users;
  - created ADT scaling policies based on NGINX and PHP-FPM metrics to explore the best approach to improve the performance of the application as it is placed under load;
  - investigated Load-Testing software platforms and began using Locust.io for load testing for all Outlandish projects that require load testing for launch and used Locust.io to load test Audience Finder on MiCADO;
  - dockerized the audience finder application, developed in T8.2, deployed and executed it through the MiCADO framework using different MiCADO releases;
- **use case 2: - evacuation planning** (Saker + Brunel University);
  - simulation manager and SakerGrid was updated to support Flexsim 17 and Flexsim 18;
  - FlexSim 18 templates have been developed to run them on SakerGrid / Cloud;
  - development of a module to create a DLL for a FlexSim to reference a database hosted on the Cloud and testing the DLL on a VM and Cloud;
  - SakerGrid was re-designed to make it compatible with VMs / Cloud and integrated with the MiCADO framework to support scaling a single application;
  - performance testing of SakerGrid on CloudSigma under different test scenarios to test scalability with MiCADO;
  - deployed the evacuation simulation application, developed in T8.2, in virtual machines and executed it using jQueuer through the MiCADO framework;
- **use case 3: social media analytics to improve citizen services** (Inycom + SARGA).
  - dockerized Magician application, developed in T8.2, for Social Media Data Analystics has been integrated in CloudSigma with the different MiCADO releases;
  - information on tourism, sports and regional, national and European elections previously collected from Twitter has been configured in Magician with the Aragon Regional Government (end user) to stress test MiCADO;
  - information collected from Twitter has been integrated with other data sources (electronic administration procedures and institutional web sites) of the Regional Government of Aragon and was analyzed using external tools such as Tableau and semantic recommendations;

Task ID	Task Title	Start month	End month
T8.4	Proof of concept feasibility studies	M18	M33
Partners	UBRUN, Saker, Inycom, Outlandish, CloudSME UG, SZTAKI		

T8.4 investigated the feasibility of 26 proof of concepts demonstrators identified and selected by COLA Independent Software Vendors (Inycom, Outlandish and Saker) and technology providers (CB, CS, SZTAKI, RISE, UoW). These

demonstrators based on COLA use case applications, developed in T8.3, with some modifications (e.g. use new customer data, etc.). They have only a limited functionality as proof of concept demonstrators. They will promote the MiCADO framework and maintain sustainability after the COLA project. These demonstrators can become the basis for full implementations on a commercial basis after the COLA project. List of these demonstrators and partners who managed them are as follows:

Saker
- evacuation service, high-performance digital twin simulation analytics;

Brunel
- discrete event simulation to optimize manufacturing using JaamSim, agent based model simulation (ABM) using Repast, agent-based micro-simulation using PALMS, agent-based simulation using FLEE, High Speed Simulation Analytics using D-SIMLAB;

Outlandish
- managing social media presence using Social Monitor, using feature branches in website development, managing school cuts in public funding, optimizing website hosting through shared hosting;

Inycom
- Competitors Alerts, clinical mammography using CAROL as deep learning tool, predictive analysis of the evolution of assets-related KPIs using MainRail, testing software applications using the Integrated Testing Solution, evaluating application status, discrete event simulation in manufacturing to support decision making using MAGOS;

TAA
- Attendance Analysis Service, extending Audience Finder to new sectors, extending Audience Finder to new countries;

SZTAKI
- data management in cloud storage using DataAvenue;

CloudSME
- WordPress HKN, NextCloud on HKN, MiCADOscale HKN, Autoscale as a Service (AaaS)

UoW
- CityMOS simulation

WP8 objectives and relevant achievements

Task 8.3

Objective 8.3 To develop near to operational level pilots and demonstrators using MiCADO services for the targeted use cases.

Objective 8.4 To provide feedback based on usability, security and cost/performance ratio of the targeted use cases to further improve the MiCADO framework.

- COLA use case applications reached near operational level, i.e. they have been described in ADTs, deployed and executed in he Cloud through the MiCADO framework;
- end users created test scenarios for COLA use case applications to assess the benefits of running them with MiCADO to scale up and down cloud resources automatically;
- three COLA use cases have provided significant and vital feedback to WP5-WP7 to improve application description, application deployment and execution and security services needed to run these applications. These improvements have been provided by platform developers in successive releases of MiCADO during the project;
- application developers have become skilled in the different MiCADO services (Docker, Kubernetes, Prometheus, Grafana, Ansible, etc.) and able to migrate other applications to the Cloud;
- adapting a DevOps methodology pipeline of Wordpress applications to MiCADO;
- deploying and running Windows applications are now supported by the MiCADO framework using virtual machines;
- applications can be run with MiCADO on Microsoft Azure;
- deliverable D8.3 “COLA near to operational level pilots and demonstrators” has been submitted;

Task 8.4 - Objective 8.5: To investigate the feasibility of 20 additional use-case scenarios based on the MiCADO framework for public sector and SME customers of the COLA software providers.

- 26 proof of concept demonstrators have been assessed and developed;
- in some of these proof of concept demonstrators new MiCADO users have been engaged (e.g.: HKN, Gradiant, Ingecontrol, etc.), contributing to a dissemination of the technology among other software vendors and cloud providers;

- CloudSME created the first commercial project (NextCloud) using the MiCADO framework;
- project partners have started to use Docker containers in most of their projects making them suitable for the MiCADO framework;
- deliverable D8.4 “Proof of concept feasibility studies” has been submitted;

Deviations from the Grant Agreement (Annex I + Annex II) in WP8

Submission deadline of deliverable D8.3 “COLA near to operational level pilots and demonstrators” and D8.4 “Proof of concept feasibility studies” were rescheduled due to the project extension.

4. Impacts

COLA has made significant progress both in creating the MiCADO framework and deploying and running applications in the Cloud. We are summarizing progress made in COLA towards the expected impacts in M19-M33 in Table 4.1-4.6.

Expected Impact 1:	**Increase Europe's technological capacity and competitiveness through the development of advanced cloud solutions.**
Contribution by the COLA Project	The COLA project will significantly **enhance the state of the art in cloud technologies** by developing a generic framework to support cloud application developers when utilising the dynamic elastic capabilities of underlying heterogeneous distributed IaaS cloud solutions. The project will demonstrate via relevant industry case-studies how **Europe's technological capacity and competitiveness will be increased** in key areas as a result of the MiCADO framework. The project case-studies will cover four distinct application areas (manufacturing companies, web application developer companies, local authorities, and evacuation planning) that are widely relevant to a large number of SMEs and public sector organisations. Although the case-studies will be implemented for COLA project partners directly, their relevance for other similar organisations in the same sector will also be highlighted. Furthermore, the project will elaborate additional potential application areas where a large number of SMEs and public sector organisations will be targeted with focused marketing and dissemination campaign (for details please see Section 2.2). Moreover, as the reference implementation of the MiCADO framework will be open-source, it will be easily available and accessible for the larger developer community.
Indicator Target	Number of impact demonstrators on how Europe's technological capacity and competitiveness will be increased in key areas. 4 impact case studies (for the four targeted areas) to be published by the end of the project (M30). For detailed measures regarding the impact of each case-study please see section 2.2.1.

Table 4.1 - Contribution to impact 1 set out in the work programme

COLA developed MiCADO as a generic open source pluggable state of the art framework that supports flexible and optimal deployment and run-time orchestration of applications in the Cloud. The framework deploys and executes existing non-cloud aware applications in IaaS Clouds using their dynamic capabilities on demand focusing on the orchestration layer. It is based on existing low-level cloud container technologies (e.g. Docker), management (Docker Swarm and Kubernetes) and orchestration solutions, and existing standards (e.g. TOSCA) using well-defined standardised interfaces to avoid dependence on one particular cloud technology. WP5-WP7 created 15 releases of the framework. The first MiCADO releases used Occopus as cloud orchestrator and Dock Swarm as container orchestrator. In later releases Kubernetes replaced Docker Swarm as container orchestrator. COLA also created a proof of concept implementation in which Terraform is used as cloud orchestrator. These developments confirm that the MiCADO framework is generic and pluggable, i.e. its services are not restricted to particular technologies and can be implemented using different technologies and services. MiCADO provides the missing link between existing non-cloud aware applications and the dynamic capabilities of IaaS Clouds by allowing connecting to multiple technology implementations on demand. It can access multiple cloud middleware (e.g. Amazon EC2, CloudSigma, Microsoft Azure, OpenStack and OpenNebula) and generic cloud access layers (e.g. CloudBroker Platform).

Running application in the Cloud in some application areas, such as public sector organizations and Small- and Medium-sized Enterprises (SME), is still relatively low due to limited application-level flexibility and shortages in cloud specific skills. The MiCADO framework accelerated take up of cloud computing in these areas addressing application- and infrastructure-level complexity. It allows Application Developers to describe their applications in the TOSCA based Application Description Templates (ADT) and upload these descriptions into a publicly available repository in GitHuB. Application Developers and End Users can download these descriptions and submit them to the MiCADO framework to deploy and run the applications in the Cloud. WP8 created near production version of 3 COLA use case applications (use case 1: audience finder application - Outlandish + The Audience Agency; use case 2: evacuation planning- Saker + Brunel University; and use case 3: social media analytics to improve citizen services - Inycom + SARGA) and 1 proof of concepts demonstrator (data transfer among different type of distributed storages using Data Avenue – CloudSME UG + SZTAKI). WP8 also identified and investigated further 25 proof of concepts demonstrators (25 of these 26 demonstrators presented in deliverable D8.4) that cover wide range of applications areas, such as manufacturing, public

services, SMEs, etc. WP8 defined the expected financial and technical impacts and TRL level of these demonstrators. WP5 and WP8 developed and uploaded Application Description Templates of these demonstrators to the MiCADO Repository in GitHub. WP6 and WP8 deployed and tested the demonstrators in the Cloud using the MiCADO framework.

Expected impact 2:	**Increased and predictable performance of cloud offerings, facilitating deployment of critical applications and services.**
Contribution by the COLA Project	The COLA project, based on existing technologies, tools and standards, will develop a generic framework that will enable cloud applications to fully utilise the dynamic and elastic capabilities of underlying IaaS clouds. As a result, the **performance** of these applications can be **optimised** taking both **execution/response time** and also **economic cost and viability** into consideration. Application developers and operators will be able to set quality of service, security, performance and economic requirements towards applications that will be monitored and the deployment will automatically adopt in case of any violation. Moreover, operators can review and modify these pre-set requirements any time. As a result of this optimised price/performance ratio, cloud applications will be more feasible and attractive for SMEs. Moreover, mission critical applications by public sector organisations, such as local authorities and the evacuation of public places, will be efficiently and reliably run on cloud computing infrastructures.
Indicator Target	Performance benchmarking and analysis of production quality near operation level demonstrators. **4** performance benchmarking experiments and their subsequent analysis to be published by M30. (3 from the demonstrators and 1 from the proof of concepts).

Table 4.2 - Contribution to impact 2 set out in the work programme

Public sector organisations and SMEs want to run applications in the Cloud in a cost-efficient, flexible, seamless and secure way. To meet these requirements COLA extended TOSCA to describe applications. WP5 elaborated the Application Description Template (ADT) to manage two-level topologies of containers and virtual machines and QoS properties as policies since the MiCADO framework runs applications in containers deployed in virtual machines. WP5 extended the TOSCA Policy Specification by several deployment, scaling and security sub-policies. Application Developers can create ADTs specifying topology and QoS parameters of applications, such as costs, execution deadlines, performance, security etc. as policy parameters. They can upload ADTs to the MiCADO Repository in GitHub and publish them. Application Developers can search, download the published ADTs and modify them to deploy and run their own applications.

To support Application Developers WP5 and WP8 created and made 2 topology and 8 policy skeletons available in the MiCADO Repository in GitHub. WP5 and WP8 elaborated ADTs of 3 COLA use case applications and 1 COLA proof of concepts demonstrator (data transfer with Data Avenue) and uploaded them to the repository. Use case owners deployed and ran these applications in the Cloud submitting their ADTs to the MiCADO framework. The benchmark results proved that the scaling policies can deliver the expected cost, performance and execution parameters. WP8 presented the benchmark results of the COLA use cases and the Data Avenue demonstrator in deliverable D8.3. Further, WP5 and WP8 also developed and uploaded ADTs of the proof of concepts demonstrators repository. These demonstrators are described in deliverable D8.4 “Proof of Concept Feasibility Studies”.

Expected Impact 3:	**Increased trust in clouds through stronger security and data protection practices, including open and auditable solutions for data security. Increased control by users of their data and trust relations.**
Contribution by the COLA Project	The COLA project will work with novel principles for security policy enforcement using the MiCADO framework. This includes principles for verification of cloud resources such as computing nodes *prior-to* deployment of applications in cloud infrastructures as well as transparent (from end-user point of view) encryption of data at rest on cloud storage resources. This implies a **thoroughly auditable and open solution** with high level of data protection when execution of arbitrary applications is taking place in open cloud environments. Even though similar approaches have been developed in previous research projects, they have not yet been integrated into production-ready cloud orchestration SW – a gap that COLA project aims to cover. Furthermore, various applications have different requirements with respect to data protection and cloud resource verification. To address this, we plan to develop a security enforcement module that will interpret novel formats and principles regarding application security specifications. This will help

	application domain security to express cloud execution and data protection requirements to cloud development. Consequently, this enables data owners to exercise **direct control** of the trust and protection level of the applications executing in a heterogeneous cloud infrastructure. Finally, automation of security services will both optimize the overall infrastructure in an organization and allow security administrators to focus on more proactive tasks. As a result, the solid security controls to be offered by COLA will have a significant impact on the deployment of trusted distributed architectures.
Indicator Target	Detailed security analysis of implemented COLA case-studies to showcase the achieved increased trust by stronger security and data protection practices, and control by users of their data and trust relations. **4** security analysis case-studies (3 from the demonstrators and 1 from the proof of concepts) to be published by M30.

Table 4.3 - Contribution to impact 3 set out in the work programme

WP7 analyzed the security landscape in cloud orchestration, identified the prospective security threats in the MiCADO framework, developed the required security model and defined the security architecture for the MiCADO framework to deliver the security services required by public sector organisations' and SMEs' applications. WP7 also investigated security requirements of COLA use cases and produced 4 security case studies: 1 for each COLA use case 1 for one of the proof of concepts demonstrators (WordPress HKN). The security case studies were presented in deliverable D7.1 "COLA security requirements".

Considering the security requirement WP7 designed the security architecture around the Security Policy Manager that provides central management for security services (or security enablers). It follows the philosophy of pluggable architecture. As a result, the enablers can be easily integrated with the actual implementations of the MiCADO services. The Security Policy Manager handles several security enablers, such as Image Verifier to check container image, CryptoEngine to provide cryptographic functions, Credential Manager to provide authentication and authorization services to hinder user impersonation attacks, Credential Store to provide sensitive information storage and Zorp to provide firewall and TLS/SSL. These security enablers are the key security services to implement the required security mechanisms in the MiCADO framework to make it a secure deployment and execution environment.

Expected Impact 4:	**Experimentation across a variety of settings that enhance Quality of Experience and contribute to standardisation and interoperability. Integration with other international initiatives for large-scale global experimentation.**
Contribution by the COLA Project	The MiCADO concept plays a very similar role in cloud computing as to MPI (Message Passing Interface) played in parallel computing on supercomputers. MPI provides a high level API that can be added to the business logic of parallel applications without changing their business logic. This resulted in a very successful and revolutionary change in the development and spread of parallel computing applications. Beyond that application development became much simpler than it was before it also made parallel applications highly portable among different kind of parallel computers. At the end MPI became an accepted standard and all supercomputing vendors implemented the MPI API in an optimized way to achieve the highest possible performance of MPI applications on their supercomputers. The goal of MiCADO is very similar to MPI. We would like to define a high level API that can be added to the business logic of applications without changing their business logic in order to enable their execution on various cloud systems in a portable and efficient way. If the MiCADO concept is successful it can lead to a similar **standardization process** that was used for the MPI concept. As a consequence MiCADO's impact could be much higher than simply providing usable cloud solutions for several industrial and public sector applications. In a long term it can revolutionise how to create portable and efficient cloud applications with minimal development effort. From the cloud **interoperability** point of view it will also have significant impact showing that from the usability and scalability points of view the most important aspect is to access as many cloud resources as needed without changing the business logic of the application, without deep learning of cloud technology, and without forcing existing clouds to intercommunicate to each other and exchange tasks and jobs. There is a significant difference between the MPI and MiCADO concepts. MPI has never targeted scalability and the ability to run the same parallel application simultaneously on several supercomputers in a dynamic and scalable way. However, in case of clouds this is the most important objective and since it requires the simultaneous access of several

	clouds it has to be able to handle the different security mechanisms of the various cloud systems. This issue can be solved at two levels: standardizing the security mechanisms of the various cloud systems or hiding the difference of these security mechanisms at a higher level layer like the MiCADO layer. In this project we will follow the second approach but as a result we will be experts of understanding the differences and similarities of the different security approaches and hence members of the COLA project can significantly **contribute to future standardization efforts** of cloud security mechanisms.
Indicator	Large scale experimentation via a set of proof of concept case studies that will demonstrate the applicability and advantages of the MiCADO framework in wide variety of application areas.
Target	**20** proof of concept experiments to be implemented by M30.

Table 4.4 - Contribution to impact 4 set out in the work programme

The MiCADO framework has a pluggable and technology agnostic architecture. MiCADO services are implemented as micro-services to support plug-ability and technology agnosticism. According to this approach micro-services can be replaced by other micro-services of the same functionality to enables interoperability of MiCADO services. As a result, the MiCADO API is able to manage different cloud and container orchestrators, policy submitters and enforcers. For example the early MiCADO releases used Docker Swarm as container orchestrator and Occopus as cloud orchestrator while latest releases Kubernetes as container orchestrator.

MiCADO manages applications as black boxes. Applications are specified in Application Description Templates (ADT) that is based on OASIS standard Topology and Orchestration Specification for Cloud Applications (TOSCA). WP5 extended the TOSCA Policy Specification and defined several sub-policies, such as deployment, scaling and security sub-policies. COLA established contacts with OASIS, the standardisation body behind TOSCA, and started contributing to TOSCA standardisation efforts. To deploy and run applications in the cloud first, Application Developers create either container or virtual machine images of the application and upload these images to a repository. Next, they describe the application topology and policies using ADTs. Finally, they submit the application description to the MiCADO framework that deploys and runs the application. None of these steps require modification of the application itself.

WP8 identified 26 proof of concepts demonstrators (See details in deliverable D8.4 “Proof of Concept Feasibility Studies”) that cover wide range of applications areas as prospective MiCADO demonstrators. The work package defined the expected financial and technical impacts and TRL level of these case studies. WP5 and WP8 developed the Applications Description Templates of all proof of concepts demonstrators and uploaded them to the MiCADO Repository in GitHub. WP6 and WP8 deployed and executed the first version of these demonstrators through the MiCADO framework.

Expected Impact 5:	**Increased readiness for adoption of trustworthy cloud-based solutions for SMEs and public sector organisations, spanning from generic enabling services to specific applications.**
Contribution by the COLA Project	The COLA project will develop and demonstrate **production or near production quality services both at the level of generic enabling services and also specific applications**. The MiCADO framework and its reference implementation will consist of a set of open-source services that application developers can utilise to make their cloud applications more adaptive. MiCADO will address both the dynamic scalability of these applications and also the application of suitable security solutions to enable trustworthy cloud solutions. MiCADO services will **generically enable a wide range of applications** to utilise clouds in a more secure and efficient way. In order to demonstrate the applicability of such generic enabling services, the COLA project will design and implement **large scale demonstrators in close to operational settings involving both SMEs and public sector organisations**. The demonstrators will showcase how specific applications can be developed on top of the MiCADO framework and will illustrate what benefits SMEs and public sector organisations can gain when utilising the framework in their applications.
Indicator	Number of SME and public sectors demonstrators implemented and disseminated to illustrate increased readiness for adoption of trustworthy cloud-based solutions.
Target	**3** near operational and **20** further proof of concept SME and public sector demonstrators are implemented and widely disseminated by M30.

Table 4.5- Contribution to impact 5 set out in the work programme

COLA developed the MiCADO framework as a generic cloud enabler service. The framework is open source and technology agnostic built on open source solutions, for example Docker Swarm, Kubernetes, Occopus, Terraform and Prometheus, and standard such as, TOSCA. The MiCADO framework processes TOSCA based application descriptions (ADTs), deploys and executes applications on multiple clouds, such as AWS EC2, CloudSigma, Microsoft Azure, etc. through the CloudBroker Platform. The applications deployed and executed according to their QoS parameters, such as cost, execution, performance and security requirements specified in policies. For example cloud resources can be scaled up and down as given in scaling sub-policies.

In M01-M18 WP8 created the proof of concept implementation of 3 COLA use case applications. In M19-M33 WP8 further developed these applications. They reached the near production level implementation phase. WP8 also identified and investigated 26 proof of concepts demonstrators covering wide range of application domains from high-performance applications to web hosting and we applications, from Artificial Intelligence to social media. (See details in deliverable D8.4 "Proof of Concept Feasibility Studies"). WP5 and WP8 developed the Applications Description Templates of all proof of concepts demonstrators and uploaded them to the MiCADO Repository. WP6 and WP8 deployed and executed the first version of these demonstrators through the MiCADO framework.

Expected Impact 6:	**Demonstration, through appropriate use cases, of the potential to improve the competitive position of the European cloud sector and to facilitate the emergence of innovative business.**
Contribution by the COLA Project	The COLA project has **carefully selected** its **use-cases** in order to demonstrate potential application areas of the developed technology that have large impact and wide coverage. The application areas are represented by appropriate project partners. However, each of the use-cases is relevant and important for a wider sector of SMEs and/or public sector organisations, and not only for the actual project partners. These specific sectors, including manufacturing SMEs, web developer companies, local authorities and evacuation planners, will be specifically targeted by dissemination and marketing campaigns. As a results, European companies can use European cutting edge technology, in the above four sectors and beyond, to **improve their competitive position via offering innovative cloud based services and solutions**.
Indicator	Near operational level and proof of concept demonstrators of real-life industry use-cases.
Target	**3** near operational and **20** further proof of concept SME and public sector demonstrators are implemented and widely disseminated by M30.

Table 4.6 - Contribution to impact 6 set out in the work programme

In M19-M33 the COLA use case applications reached the near production level implementation phase. WP8 also identified and investigated 26 proof of concepts demonstrators covering wide range of application domains from high-performance applications to web hosting and we applications, from Artificial Intelligence to social media. (See details in deliverable D8.4 "Proof of Concept Feasibility Studies"). WP5 and WP8 developed the Applications Description Templates of all proof of concepts demonstrators and uploaded them to the MiCADO Repository. WP6 and WP8 deployed and executed the first version of these demonstrators through the MiCADO framework.

WP2 and WP5-WP7 developed on-line tutorials and webinars to explain how create Application Description Templates and how to deploy and run application through the MiCADO framework in the cloud. WP2 and WP8 also created videos demonstrating how to specify, deploy and execute the COLA use cases through the MiCADO framework in the Cloud. The videos were uploaded to the COLA website to promote the MiCADO framework. WP2 in cooperation with the COLA technology developers presented these tutorials at several European and national dissemination events and workshops. All on-line tutorials and webinars are available at the COLA website: https://project-cola.eu.

5. Updates in DoA and Use of Budget/Resource

5.1. Access provisions to Research Infrastructures

This sub-section is not relevant because COLA does not provide access to Research Infrastructures.

5.2 Resources used to provide access to Research Infrastructures

This sub-section is not relevant because COLA does not provide access to Research Infrastructures.

5.3 Update of the plan for exploitation and dissemination of result (if applicable)

COLA upgraded the COLA Dissemination Plan outlined in DoA and presented it in deliverable D2.1 "Dissemination plan and project public website". According to the upgraded plan WP2 put more emphasis on dissemination events, such as conferences, exhibitions, fairs, workshops; social media channels, such as including Twitter, Facebook and LinkedIn; and on training activities, such as code camps, on-line tutorials and webinars. The COLA partners attended a number of dissemination events to promote COLA in academic and non-academic communities. To raise awareness and interest of stakeholders, the project prepared and conducted several on-line tutorials and webinars. Online materials such as user-guides and tutorials were written and published on the project's public website (http://www.project-cola.eu), newsletter, and social media channels (incl. Twitter and Facebook).

WP3 elaborated the COLA Exploitation and Sustainability Strategy relying on inputs of the project partners putting particular focus on non-academic partners and COLA use cases. All partners provided their inputs, such as, their IPR management, exploitation and sustainability plan, etc. In addition non-academic project partners provided their business models and the relevant inputs. WP3 presented COLA exploitation and sustainability strategy and IPR management in the deliverable D3.3 "Final commercial exploitation and sustainability report".

5.4 Update of the data management plan

COLA project partners monitored all activities that might affect DMP. Based on their inputs no changes were required in the COLA DMP. As a result, the DMP, presented in D1.3, was not modified.

5.5 Follow-up of recommendations and comments from the first review

COLA addressed the comments and recommendations of Reviewers outlined in the General Project Review Consolidated Report as outlined below:

1. **overall assessment**

addressing comments on deliverables

- D2.1 – Dissemination plan and project public website
  - the report has been modified including redefinition of the target audience, providing more details about the dissemination activities and explanation of how to reach large user communities;
- D2.2 – First periodic dissemination report
  - numbers of organisations and users involved in COLA dissemination activities, numbers of people following COLA on Facebook and Twitter have been upgraded;
  - more details about multipliers organisations COLA was in contact have been given;

addressing comments on the COLA website

- users can register with the website to be able to test the latest MiCADO releases;
- information about the MiCADO releases have been uploaded on regular basis;

addressing comments on future works

- market and competitor analysis
  - WP3 analysed the overall market and competitors for the MiCADO framework – See details in deliverable D3.3- and proposed two MiCADO branches: MiCADOscale for commercial and MiCADOcommunity for academic users;
- sustainability of the MiCADO framework
  - WP3 developed a sustainability strategy presented in deliverable D3.3;
- using social media channels
  - WP2 evaluated the use of social media channels and recommended to use Facebook, LinkedIn and Twitter;
- supporting commercial usage of the MiCADO framework
  - COLA created two MiCADO branches: MiCADOscale (commercial branch) and MiCADOcommunity (academic branch) based on WP3 recommendations on sustainability;
- final project report

- D1.5 presented the summary of activities and achievements of each work package at task level instead of describing project partners' contributions;
- reported PMs and budget spent
  - WP1 and project partners analyzed the number of reported PMs and budget spent in M01-M18;
  - based on this analysis project partners developed a plan on how to use PMs and spend budget in M19-M30 and agreed on regular monitoring of the project budget;

2. comments on objectives and workplan

addressing comments on objectives and workplan

- WP3 Commercial Exploitation and Sustainability
  - WP3 developed a sustainability strategy for the MiCADOscale and presented it in deliverable D3.3;
  - WP8 described the sustainability strategy of COLA project partners to support further development and maintenance of the MiCADO framework;
- WP6 Microservice Execution and Deployment Layer
  - The work package developed a roadmap for developing new MiCADO releases and followed this roadmap to create 9 new MiCADO releases;
  - The COLA website is regularly upgraded to provide information about the MiCADO releases, for example currently the website provides information about the latest MiCADO release v0.8.0. See at https://project-cola.eu/

addressing comments on scientific and technical relevance

- Scientific and technical relevance
  - COLA created two MiCADO branches: MiCADOscale for commercial and MiCADOcommunity for academic users;
  - These two branches give clear message about the target groups COLA is addressing and position the MiCADO framework in both developer and end user communities;

3 comments on impacts

- gender balance
  - at least 25% of staff worked for the project are female. See details of gender balance are given in the Table – Gender data on the Participation Portal;

4 implementation

- project management and reporting
  - deliverable D1.5 contains data about PMs used by partners and work package and budget spent by partners in COLA in Section 5.7 of this deliverable;
- disseminating project achievements and results
  - WP2 revised and restructured the COLA website, the restructured website contains "about", "media", "experiments", "MiCADO releases" and "consortium" page;
  - on the revised homepage there is a link to the MiCADO homepage available at https://micado-scale.eu/;
  - WP2 updated the COLA website more frequently in M19-M33 than in M01-M18 uploading information about the latest MiCADO releases and information about dissemination events, MiCADO on-line tutorials and webinars;
  - WP2 also added a new webpage to the COLA website to provide information about MiCADOscale;
- market and competitor analysis
  - WP3 analyzed the cloud market and investigated the competitors. Outputs of this activity is presented in D3.2 Marketing campaign to support sustainability and commercialisation;
- data management plan in COLA
  - WP1 in cooperation with all COLA partners monitored all activities that might affect DMP. Based on their inputs no changes were required in the COLA DMP. As a result, the COLA DMP, presented in D1.3, was not modified;

5 resources

- resource management
  - WP1 asked all COLA partners to revise how they want to use their resource and how they want to spend their budget in M19-M33;
  - based on their inputs WP1 set up a contingency plan to manage efficiently and properly both the budget and PMs;
  - deliverable D1.5 contains data about PMs used at partner and work package level and budget spent at partner level in COLA in Section 5.7;

5.6 Deviations from Annex 1 and Annex 2 (if applicable)

There was a minor deviation from the DoA due to unexpected change in project partners. This deviation led to minor delays and the project consortium requested a 3 month-long extension of the project to manage these delays in application and technical developments caused by the two partner changes in M01-M18. The request was accepted and a 3 months extension was granted.

5.7 Use of budget and resources.

5.7.1 Use of resources

Tables 5.1-5.2 and Figures 5.1-5.4 present PMs used in M19-M33 and M01-M33 by project partners and work packages in COLA. Table 5.3 and Figures 5.5-5.6 outline the costs COLA partners claim and request for M19-M33 and M01-M33.

Remark. All partners forwarded the PM numbers they used and all partners but UoW sent their costs to the Project Coordinator. There is an on-going audit at UoW. As a result, Table 5.3 and Figures 5.5 and 5.6 do not contain costs to be claimed by UoW. The partners' costs are indicative. The final costs numbers will be reported in Form C and submitted to the Funding and Tenders Portal.

Persons-Months for M19-M33																				
	WP1		WP2		WP3		WP4		WP5		WP6		WP7		WP8		WP9		TOTAL per Beneficiary	
Workpackage	Actuals WP1	Planned WP 1	Actuals WP2	Planned WP 2	Actuals WP3	Planned WP 3	Actuals WP4	Planned WP 4	Actuals WP5	Planned WP 5	Actuals WP6	Planned WP 6	Actuals WP7	Planned WP 7	Actuals WP8	Planned WP 8	Actuals WP9	Planned WP 9	Actuals total	Planned total
UoW	5.76	14	4.60	5	0.00	1	6.20	6	15.97	29	10.36	16	15.31	20	28.93	6	0	0	87.13	97
SZTAKI	0.80	1	5.00	8	1.51	1	19.20	12	6.57	11	45.82	30	4.00	5	17.64	6	0	0	100.54	74
CB	0.51	1	0.81	4	5.87	10	39.81	7	0.00	3	0.00	0	0.00	0	1.37	5	0	0	48.37	30
ST	0.39	1	0.62	1	0.00	0	32.59	15	0.00	2	0.33	4	0.00	0	4.28	8	0	0	38.21	31
RISE SICS	0.50	1	3.90	3	1.87	1	2.05	4	5.57	6	0	0	13.11	26	0.00	0	0	0	27	41
CS	0.58	1	0.53	1	1.68	2	8.72	23	0.00	0	0.00	0	0.00	0	0.00	0	0	0	11.51	27
Balabit		0.4	0.00	0.1	0.00	0.1	0.00	0	0.00	0	0.00	0	0.00	0.75	0.00	0	0	0	0	1.35
INYCOM	0.60	1	1.06	2	2.40	4	0.00	0	0.00	0	0.00	0	0.00	0	16.11	32	0	0	20.17	39
SARGA	0.00	1	0.00	2	1.50	2	0.00	0	0.00	0	0.00	0	0.00	0	9.20	16	0	0	10.7	21
NOW		0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0	0	0	0
UBRUN	0.85	1	1.90	3	0.81	1	0.00	0	0.00	0	0.00	0	0.00	0	14.80	24	0	0	18.36	29
SAKER	1.94	1	0.35	1	0.27	3	0.00	0	0.00	0	0.00	0	0.00	0	19.08	24	0	0	21.64	29
Outlandish	0.40	1	0.30	1	0.20	1	0.00	0	0.00	0	0.00	0	0.00	0	5.20	14	0	0	6.1	17
cloudSME	0.50	1	13.62	25	4.95	10	0.00	0	0.00	0	0.00	0	0.00	0	2.85	5	0	0	21.92	41
TAA	0.31	1	0.09	2	1.14	1	0.00	0	0.00	0	0.00	0	0.00	0	2.93	8	0	0	4.47	12
BalaSys		0.6	0.00	0.9	0.00	0.9	0.00	0	0.00	0	0.00	0	44.00	14.25	0.00	0	0	0	44	16.65
Total per WP	13.14	27	32.78	59	22.20	38	108.57	67	28.11	51	56.51	50	76.42	66	122.39	148	0	0	460.12	506

Table 5.1 Planned and Actual PM used by Partners and Work Packages in M19-M33

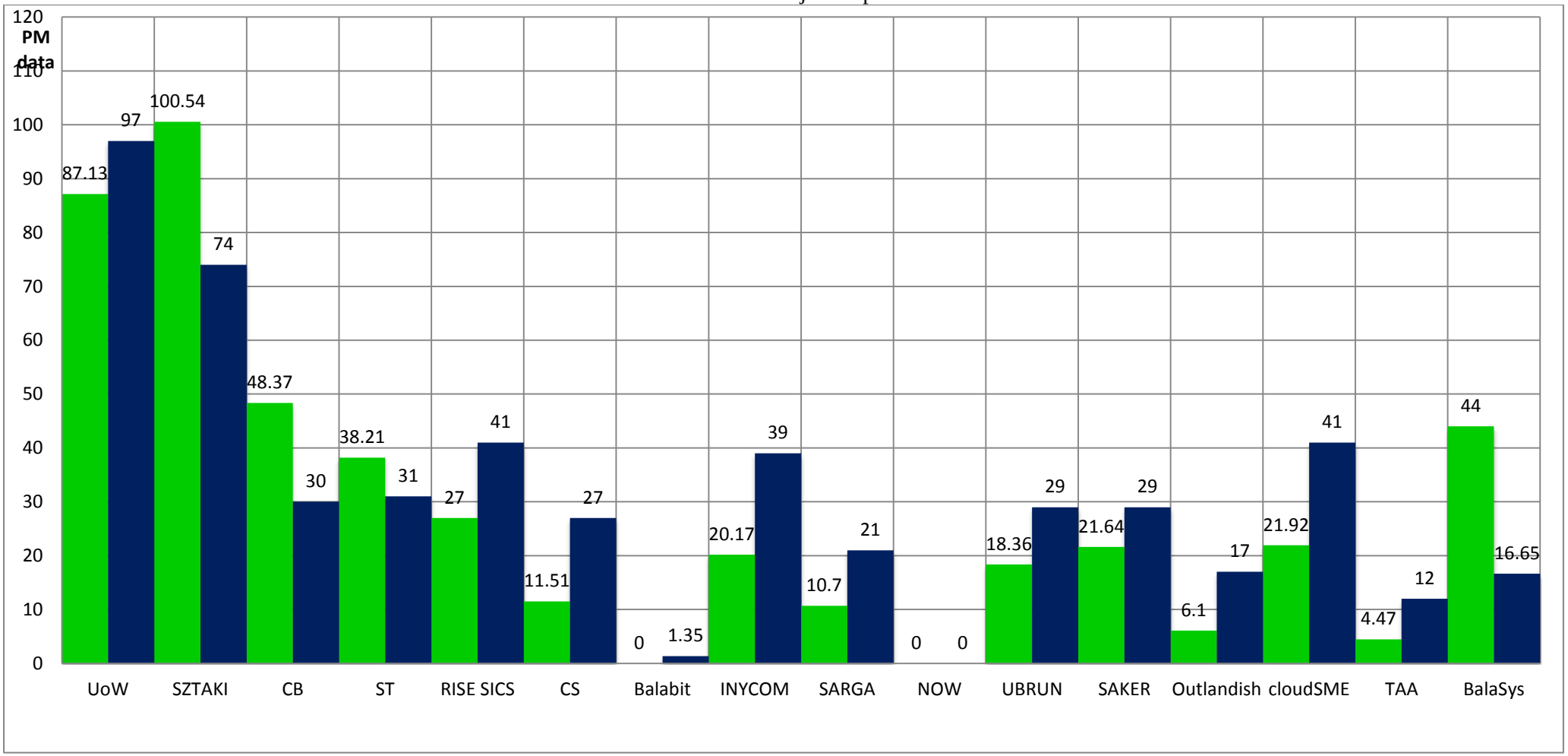

Figure 5.1 Planned and Actual PM used by Partners in M19-M33

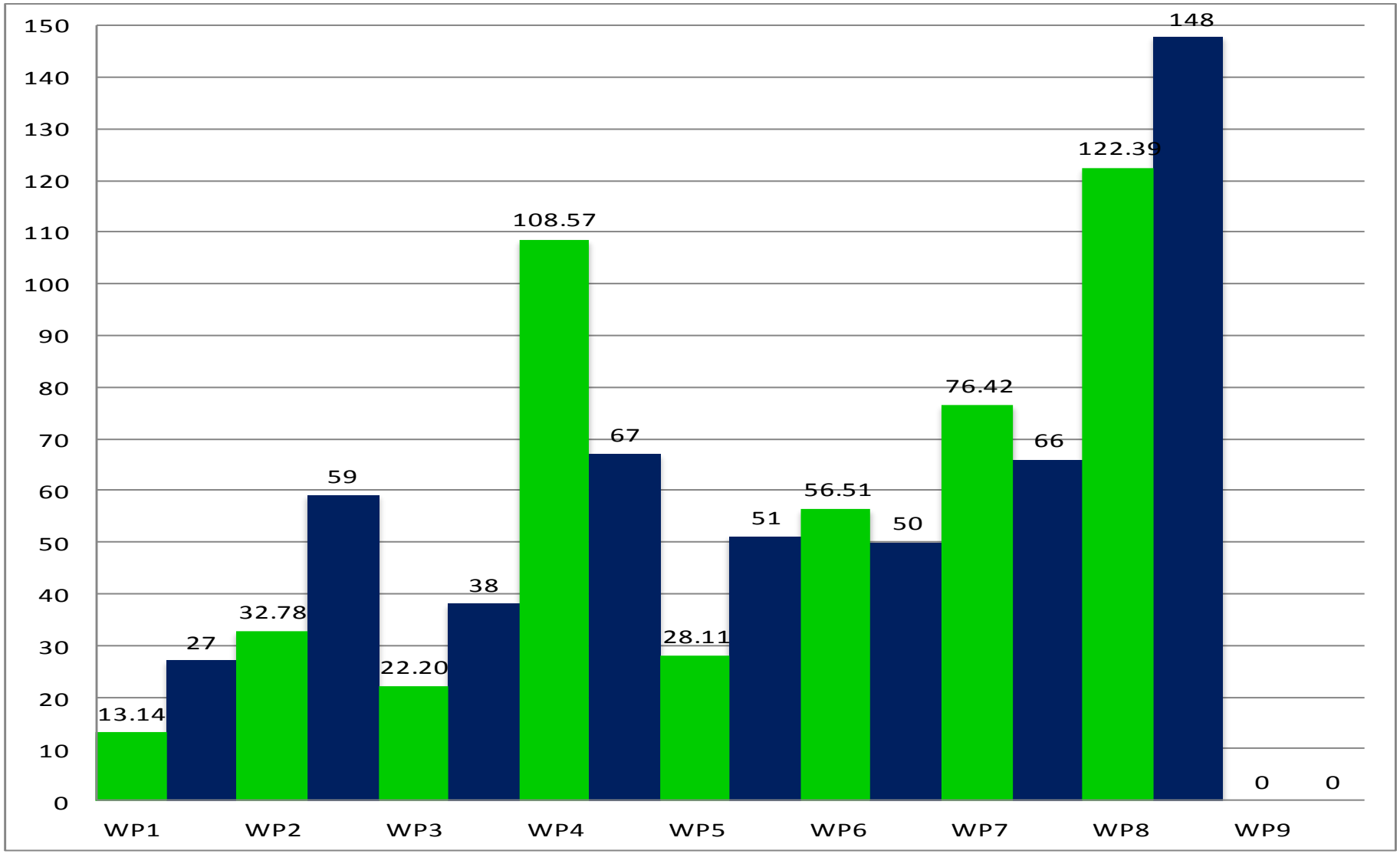

Figure 5.2 Planned and Actual PM used by Work Packages in M19-M33

	WP1		WP2		WP3		WP4		WP5		WP6		WP7		WP8		WP9		TOTAL per Beneficiary	
Workpackage	Actuals WP1	Planned WP 1	Actuals WP2	Planned WP 2	Actuals WP3	Planned WP 3	Actuals WP4	Planned WP 4	Actuals WP5	Planned WP 5	Actuals WP6	Planned WP 6	Actuals WP7	Planned WP 7	Actuals WP8	Planned WP 8	Actuals WP9	Planned WP 9	Actuals total	Planned total
UoW	8.49	14	7.62	5	0.00	1	6.62	6	34.83	29	35.42	16	28.10	20	30.25	6	0.00	0	151.33	97
SZTAKI	2.54	1	9.12	8	2.96	1	28.28	12	13.44	11	79.63	30	8.39	5	22.60	6	0.00	0	166.96	74
CB	2.01	1	0.95	4	10.08	10	44.79	7	0.00	3	0.00	0	0.00	0	1.55	5	0.00	0	59.38	30
ST	1.11	1	0.72	1	0.65	0	40.88	15	0.00	2	0.33	4	0.00	0	4.40	8	0.00	0	48.09	31
RISE SICS	1.00	1	4.90	3	1.87	1	5.55	4	6.48	6	0.00	0	25.86	26	0.00	0	0.00	0	45.66	41
CS	1.00	1	1.00	1	2.00	2	23.00	23	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	27	27
Balabit	0.40	0.4	0.10	0.1	0.10	0.1	0.00	0	0.00	0	0.00	0	0.75	0.75	0.00	0	0.00	0	1.35	1.35
INYCOM	1.20	1	2.12	2	4.80	4	0.00	0	0.00	0	0.00	0	0.00	0	32.22	32	0.00	0	40.34	39
SARGA	1.00	1	2.00	2	2.70	2	0.00	0	0.00	0	0.00	0	0.00	0	17.30	16	0.00	0	23	21
NOW	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0	0
UBRUN	1.48	1	3.12	3	1.22	1	0.00	0	0.00	0	0.00	0	0.00	0	25.49	24	0.00	0	31.31	29
SAKER	3.75	1	0.70	1	0.54	3	0.00	0	0.00	0	0.00	0	0.00	0	37.83	24	0.00	0	42.82	29
Outlandish	1.10	1	1.00	1	1.10	1	0.00	0	0.00	0	0.00	0	0.00	0	13.35	14	0.00	0	16.55	17
cloudSME	1.10	1	26.79	25	10.66	10	0.00	0	0.00	0	0.00	0	0.00	0	6.30	5	0.00	0	44.85	41
TAA	1.62	1	0.16	2	1.47	1	0.00	0	0.00	0	0.00	0	0.00	0	8.52	8	0.00	0	11.77	12
BalaSys	0.00	0.6	0.00	0.9	0.00	0.9	0.00	0	0.00	0	0.00	0	46.50	14.25	0.00	0	0.00	0	46.5	16.65
Total per WP	27.8	27	60.30	59	40.15	38	149.12	67	54.75	51	115.38	50	109.60	66	199.81	148	0	0	756.91	506

Table 5.2 Planned and Actual PM used by Partners and Work Packages in M01-M33

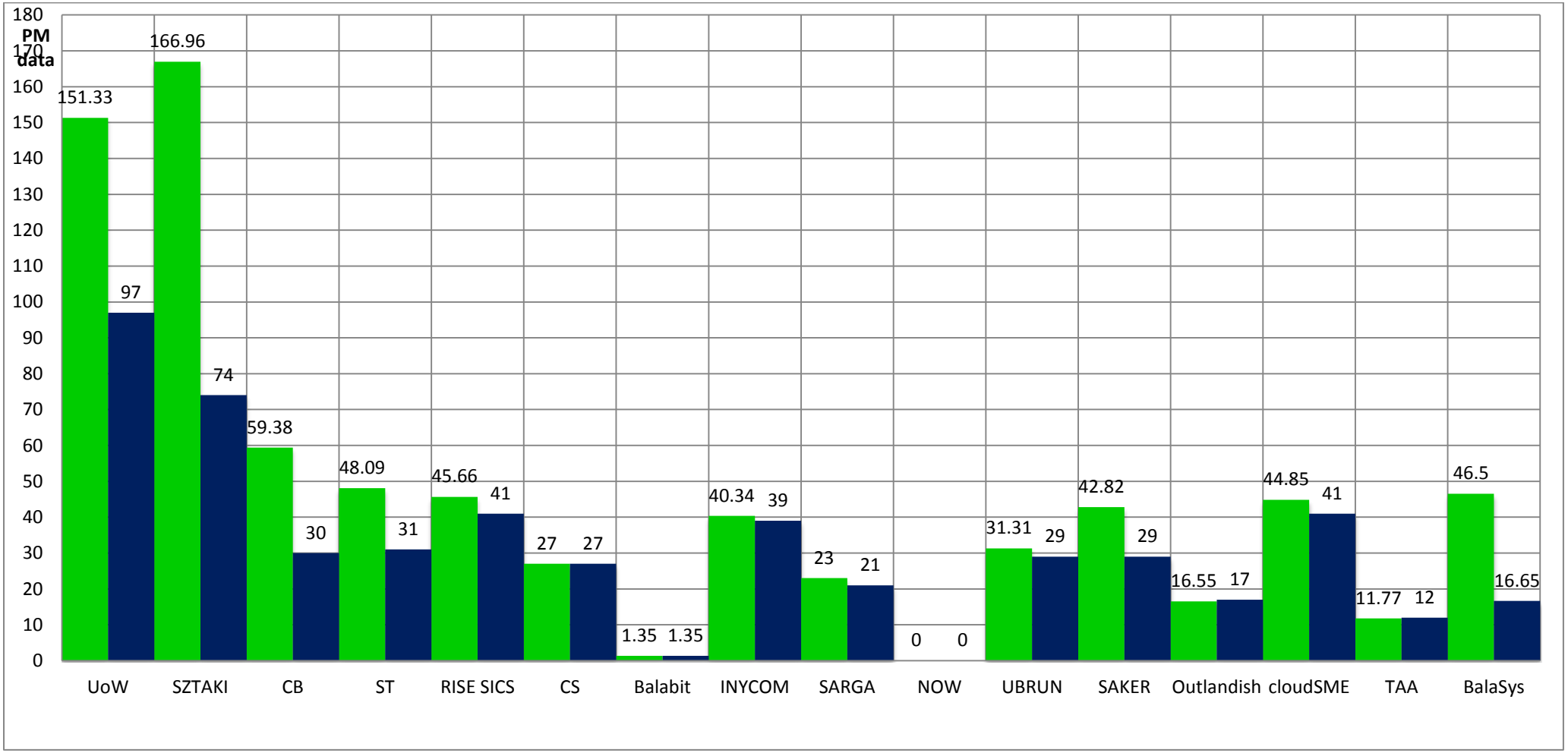

Figure 5.3 Planned and Actual PM used by Partners in M01-M33

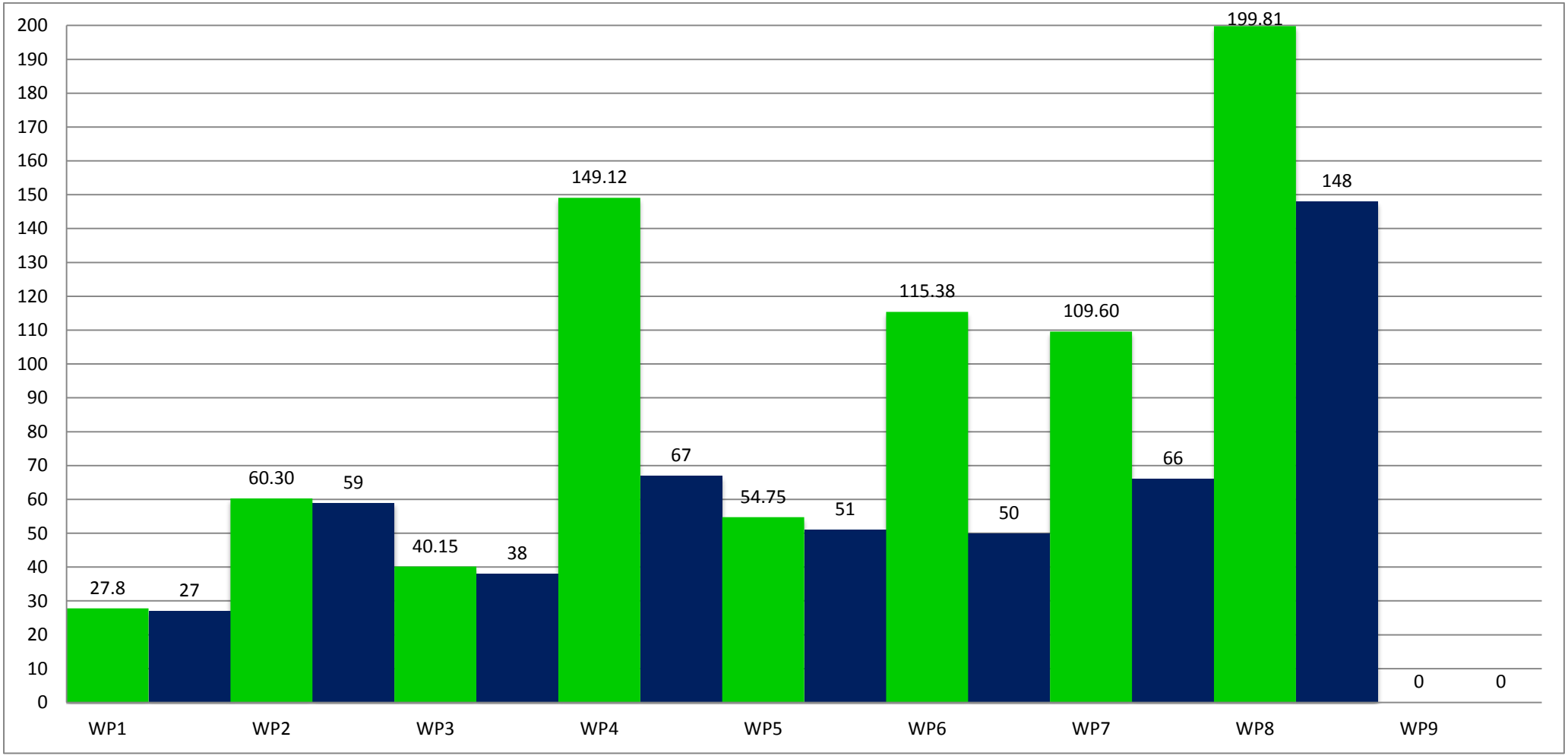

Figure 5.4 Planned and Actual PM used in Work Packages in M01-M33

	M19-M33	planned			M01-M33	planned
UoW		822188		UoW	324894	822188
SZTAKI	258477	455000		SZTAKI	477633	455000
CB	186512	264063		CB	263425	264063
ST	219023	289875		ST	289161	289875
SICS	225266	369250		SICS	355600	369250
CS	113733	172725		CS	172725	172725
Balabit	0	5114		Balabit	5114	5114
INYCOM	74731	136719		INYCOM	131979	136719
SARGA	32198	73246		SARGA	72967	73246
NOW	0	0		NOW	0	0
UBRUN	145080	248750		UBRUN	249620	248750
SAKER	61605	159250		SAKER	159250	159250
Outlandish	68,691	197698		Outlandis	192459	197698
cloudSME	136842	237300		cloudSME	273684	237300
TAA	41383	116379		TAA	108966	116379
BalaSys	148451	149816		BalaSys	158059	154200
	1711993	3697371			3235534	3701755

Table 5.3 Planned Budget and Actual Costs of Partners in M19-M33 and M01-M33

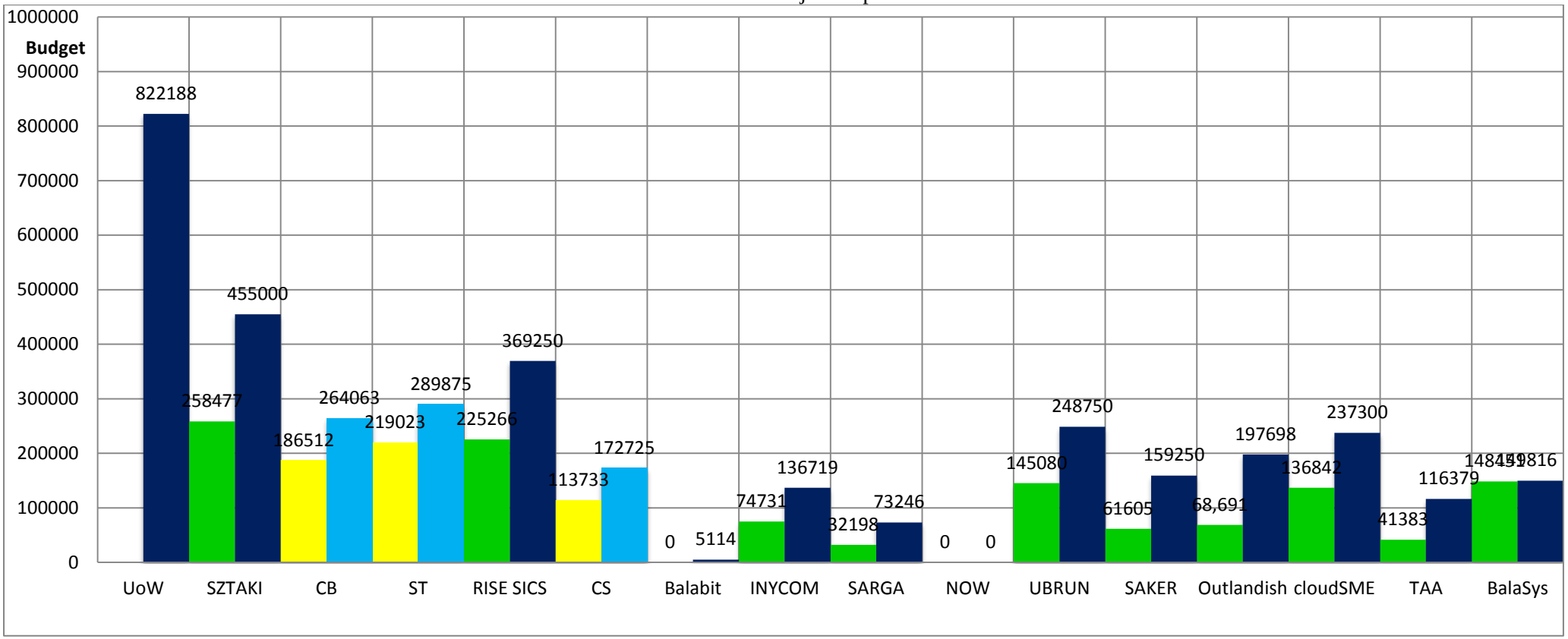

Figure 5.5 Planned Budget and Actual Costs of Partners in M19-M33

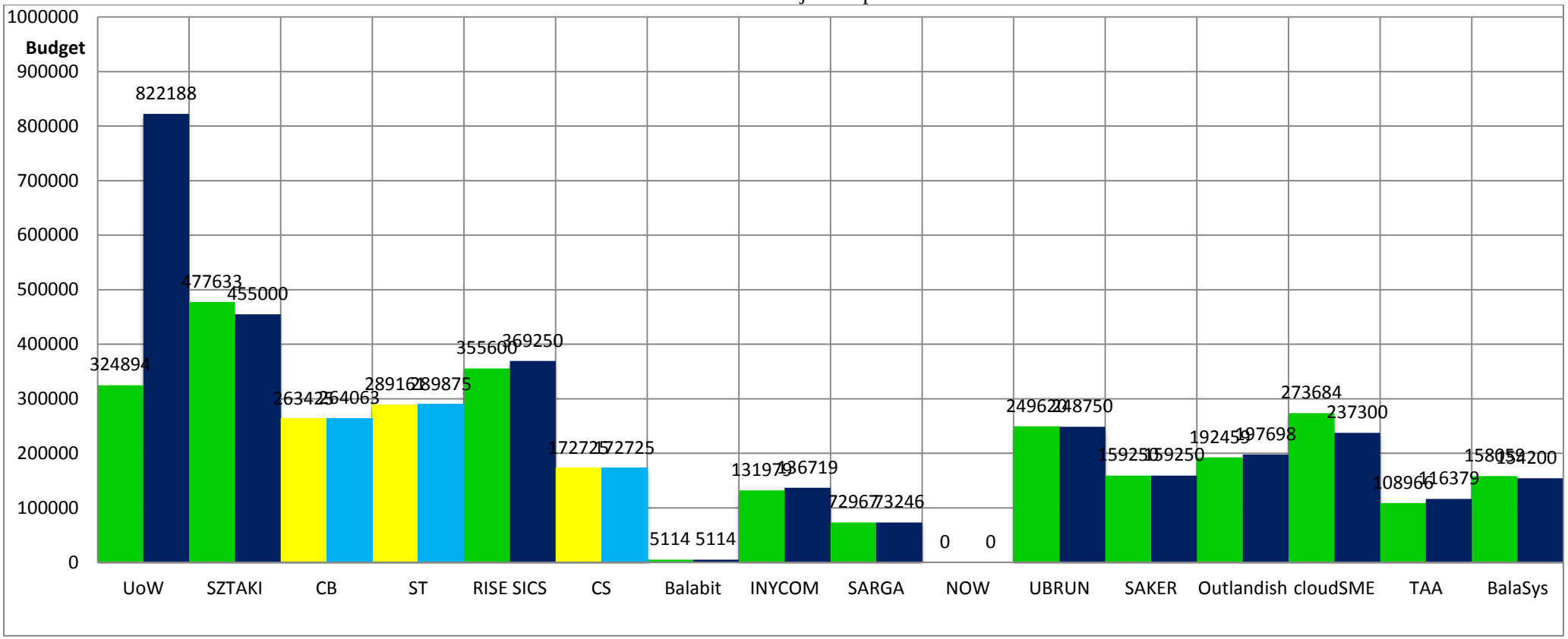

Figure 5.6 Planned Budget and Actual Costs of Partners in M01-M33

5.7.1 Explanation of budget and resource usage

Three partners (BalaSys, SZTAKI and UoW) and four work packages (WP4, WP6, WP7 and WP8) used more person months than planned in the Grant Agreement. There are two reasons behind it. First, BalaSys, SZTAKI and UoW reported more person months because it required more effort to design, implement and test the MiCADO framework than expected. SZTAKI and UoW were key partners behind the development of the MiCADO framework and they put more effort into this development. BalaSys joined the project consortium in June 2018 replacing BalaBit. It took longer to get familiarized with the security services of the MiCADO framework than previously assumed. BalaSys played key role in testing and evaluating these security services. These activities required more effort than we planned. To avoid significant overspending of their budget BalaSys, SZTAKI and UoW employed either junior researchers or PhD students instead of senior researchers. Second, COLA reported more person months for WP6 and WP7 than planned because BalaSys and UoW spent more efforts on these two work packages. WP4 also used more person months than planned because the COLA testbed and production infrastructure was absolutely essential for the development of the MiCADO framework and creating, deploying and running COLA use case and proof-of-concepts applications. To create and offer these infrastructures CloudBroker, CloudSigma and ScaleTools as commercial cloud providers and SZTAKI and UoW as academic cloud providers put more effort than previously planned. COLA put significant efforts in developing the COLA use cases to reach near production level and creating proof-of-concepts demonstrators.

5.7.2 Unforeseen subcontracting

There was no sub-contracting in COLA.

5.7.3 Unforeseen use of in-kind contribution from third party against payment or free of charges

There was no use of in-kind contribution from third party in COLA.