D6.3

Terceiras's use cases preliminary iVPP integration tests (T6.1)

AUTHORS:

Ana Carvalho, Eduardo Rodrigues (EDP NEW)

Ioannis Moschos, Napoleon Bezas, Petros Tzallas (CERTH)

António Furtado, Carlos Martins (EDA)

H2020-LC-SC3-2018-2019-2020 / H2020-LC-SC3-2020-EC-ES-SCC

EUROPEAN COMMISSION

Innovation and Networks Executive Agency

Grant agreement no. 957810

PROJECT CONTRACTUAL DETAILS

Project title	IntegrAted SolutioNs for the DecarbOnization and Smartification of Islands
Project acronym	IANOS
Grant agreement no.	957810
Project start date	01-10-2020
Project end date	30-09-2024
Duration	48 months
Project Coordinator	João Gonçalo Maciel (EDP) - JoaoGoncalo.Maciel@edp.com

DOCUMENT DETAILS

Deliverable no.	D6.3
Dissemination level	Public
Work package	WP6: Deployment, Use Cases Realization and Monitoring at LH#2 (Terceira)
Task	T6.1: Technologies Engineering and System Dimensioning (advancement of TRLs)
Due date	July 2022
Actual submission date	August 2022
Lead beneficiary	EDP

Version	*Date*	*Beneficiary*	*Changes*
0.1	20-05-2022	EDP	Initial draft and TOC proposal
0.2	08-06-2022	CERTH, EDA	Changes to TOC and initial input
0.3	10-06-2022	EDP	Added pricing and format changes to Terceira information
0.4	18-07-2022	CERTH	Included the testing methodology
0.5	22-08-2022	CERTH	Included test results
1.0	31-08-2022	CERTH, EDP	Final conclusions included

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

Executive Summary

The decarbonisation of key sectors is fundamental to allow for the energy transition of geographical islands. In IANOS, a clear pathway towards this decarbonisation is pursued by the implementation of innovative technologies and resources' management techniques. More precisely in Terceira, an intelligent Virtual Power Plant (iVPP) system will be tested, which will connect several existing assets in Terceira and compute optimal setpoints to reduce curtailment, improve the flexibility of the grid and avoid grid challenges.

For the iVPP to provide correct feedback on the management of the grid-assets, several integration tests need to be performed. In deliverable D6.3, these tests will be described and the responses of the iVPP will be examined based on the functional requirements of the Use Cases.

Deliverable D6.3 *"iVPP Use Cases' Preliminary iVPP Integration Test Report"* is included in Task 6.1 of Work Package (WP) 6 of the project IANOS. This Work Package is dedicated to the Deployment, Use Cases Realization and Monitoring at LH#2 (Terceira) and Task 6.1 in particular to the Technologies Engineering and System Dimensioning. In this context, deliverable 6.3 appears as a report on the state of iVPP connection and integration to grid-assets in Terceira, and the preliminary results on its actuation using historical data from these assets to perform the tests.

This report will present a technical description of Terceira's energy grid, including all information needed by the iVPP to perform such as the energy mix, electricity production and consumption, annual and seasonal load profiles and line diagrams of the grid. Additionally, a description of the iVPP components which will be responsible for the management of Terceira's grid-assets will be given. Finally, the integration tests to be performed will be described and the results of these tests will be presented, in order to identify any further integration that may be required. Deliverable D6.3 will provide conclusions on the state of the integration of the iVPP to other system components and allow for a first sense of how the iVPP will be managing the assets in view of a more flexible and secure grid.

The main contributors for this deliverable are the partners involved in Task 6.1, namely site managers and owners of Terceira Island and the iVPP developers.

Table of Contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

List of Figures

List of Tables

Abbreviations

BESS	Battery Energy Storage System
CD	Centralized Dispatcher
EoL	End of Life
ESB	Enterprise Service Bus
FL	Fellow
iVPP	Intelligent Virtual Power Plant
LH	Light House
WP	Work Package
RES	Renewable Energy Source
TRL	Technology Readiness Level

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

1 Introduction

1.1 Purpose and Scope

The project IANOS brings together several innovative technologies in order to pursue the efficient decarbonisation of key sectors in geographical islands. Through 9 Use Cases, the project looks at implementing technologies and management techniques to decarbonise two Light House (LH) Islands, Ameland and Terceira, and three Fellow Islands (FL), Bora-Bora, Lampedusa and Nisyros. One of the technologies to be implemented in Terceira is an intelligent Virtual Power Plant (iVPP) which will have access to the energy flows between assets in this island and provide insights on the best management procedures to adopt in order to have a more efficient asset usage, providing grid services and in general providing a better energy quality to the island.

The deliverable *D6.3 - Terceiras's use cases preliminary iVPP integration tests report,* written under task *T6.1 - Technologies Engineering and System Dimensioning (advancement of TRLs),* presents the integration tests to be performed to the iVPP decision making intelligence, using historical data from grid assets in Terceira. This report will provide the preliminary results of these integration tests, focusing on the assets involved in the Use Case 2 *"Community Supply-Side optimal dispatch and intra-day services provision",* and will examine the response of the iVPP based on functional requirements.

1.2 Structure

This deliverable will be structured as follows:

- Chapter 2: A comprehensive description of Terceira's grid is provided including all information needed by the iVPP. A description of the most important decision-making iVPP components relevant for the optimization of the usage of Terceira's grid assets is also provided.

- Chapter 3: Provides a description of the testing methodology to be used to assess the integrability between the iVPP and Terceira's grid assets. Moreover, the results of these tests will be presented here;

- Chapter 4: Further tests to be performed towards the integrability of the iVPP with other project components are described in this section;

- Chapter 5: Finally, a conclusion to the deliverable is provided.

1.3 Relation to other deliverables

Work Package 6 relates to the deployment of technologies specifically in the Light House Island of Terceira, aiming to demonstrate the several technologies and management techniques to be tested in the island and detailed in task T2.1 – Islands Requirements engineering and use case definitions.

The present deliverable is included in Task 6.1, under Work Package (WP) 6 - Deployment, Use Cases Realization and Monitoring at LH#2 (Terceira). Through D6.3, T6.1 aims now at testing and providing an insight on the results of using the iVPP management techniques to control the grid assets in Terceira.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

This deliverable relates closely to other deliverables in T6.1 and in Work Package 6, such as D6.1 - Initial TRL assessment and development of Terceira technologies roadmaps, where an overview of the Technology Readiness Level (TRL) of the iVPP was provided, as well a description of the several components of the virtual power plant. Also included in WP6 and related to this deliverable, the reports D6.5 – Terceira system integration report and D6.7 – Terceira system commissioning report, included in Task T6.3 will be fed with the conclusions of D6.3.

Beside WP6, this deliverable will also be related to other tasks and deliverables. It will have information present in D2.1 - Report on Islands requirements engineering and UCs definitions, where the Use Cases which will be the base of the integration test scenarios is described. Also deliverable D2.10 - IANOS Islands Decarbonisation Master Plan, included in Task 2.4, will be of use to better understand the role of the iVPP on the decarbonisation of Terceira.

Work Package 4 will provide the core information to this deliverable, since it is the WP dedicated to delivering the virtual power plant operational framework and components. The deliverables in task T4.1 - Cyber-Secure data monitoring and VPP Governance, T4.3 - Intelligent VPP Clusters' Segmentation, T4.4 - Optimized cross-resource VPP coordination for energy services provision and T4.6 - Virtual Energy Console, will provide a base work for the iVPP used in D6.3 and are therefore relevant for the present deliverable.

Lastly, the results of WP6, and thus the results of the iVPP integration results in Terceira included in this deliverable, will be used to achieve conclusions on the replication opportunities and scalability of the project in other EU islands. Hence, the conclusions presented in Deliverable D6.3 will be useful for WP9 – Replication/Scalability on EU Island and serve as input for the deliverables in Task 9.1 - Lighthouse Islands Replication and Scalability Plan and Task 9.2 - Fellow Islands Replication and Scalability Plan.

In Figure 1 , the relationship between the Deliverable D6.3 and other deliverables as well as respective Tasks and Work Packages is visually presented as described above.

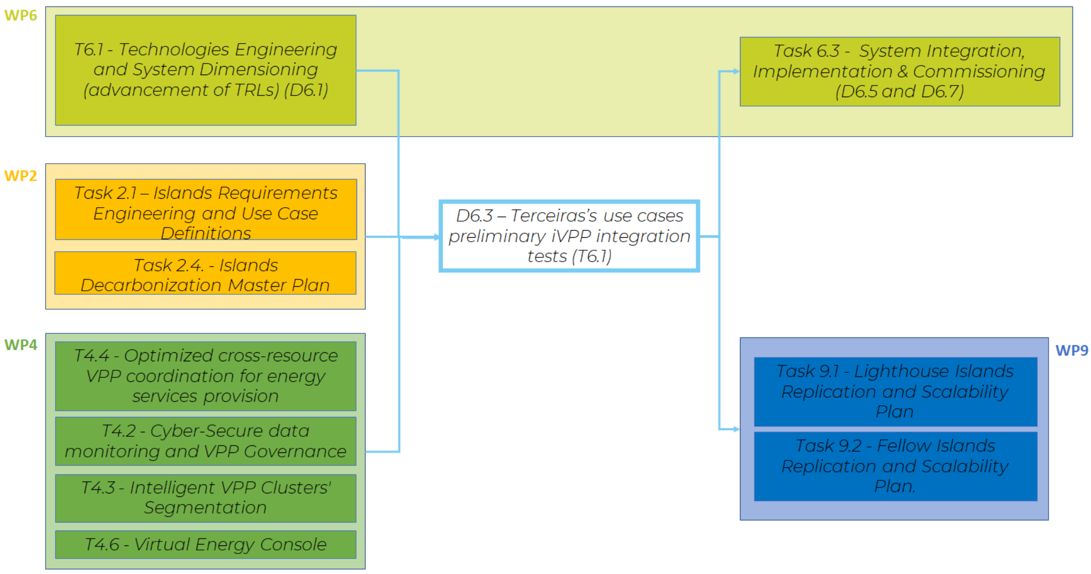

Figure 1 Relation between D6.3 and other Tasks and Work Packages within the IANOS project

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

2 Components Description and Specifications

2.1 Terceira's Facilities and Components

2.1.1 Terceira's General Description

As presented on *Deliverable 2.1. "Report on Islands Requirements Engineering and Use Case Definitions",* Terceira is one of Azores's 9 islands, and a volcanic island located in the middle of the north Atlantic Ocean 1,600 km west of Portugal. Terceira is the third largest island in the Azores archipelago, with an area of 402.2 km². Its population is 55,300 inhabitants and its economy is mostly based on the raising of livestock, production of dairy-based products and, recently, tourism. Between 2010-2018 the tourism in Terceira has grown 230%, reaching in 2018 137,920 tourists. Angra do Heroísmo the historical capital of the archipelago and part of Terceira is classified as UNESCO World Heritage Site. Terceira has a subtropical climate with mild annual oscillations. Given its volcanic origin, geothermal surfaces allow the use of geothermal resources for power generation. In 2020, 184,6 GWh of electricity were delivered to the grid in Terceira, where approximately 38% were from renewable energy sources. The fuel oil is still the dominant energy source in the island. Regarding the electricity consumption in 2020, 170,7 GWh were consumed in the island: 101,1 from Low Voltage and 69,6 GWh from Medium Voltage. The Residential Sector is the one who represents the most significant consumption. The annual peak demand was of about 32,172 MW on the 29 December at 7:30 p.m., whilst the annual off-peak demand happened on the 7 May at 04:45 p.m. and was 12,786 MW. In Figure 2 the characteristic load diagrams for Terceira islands in each of the four seasons can be identified, as well as the source of the energy provided.

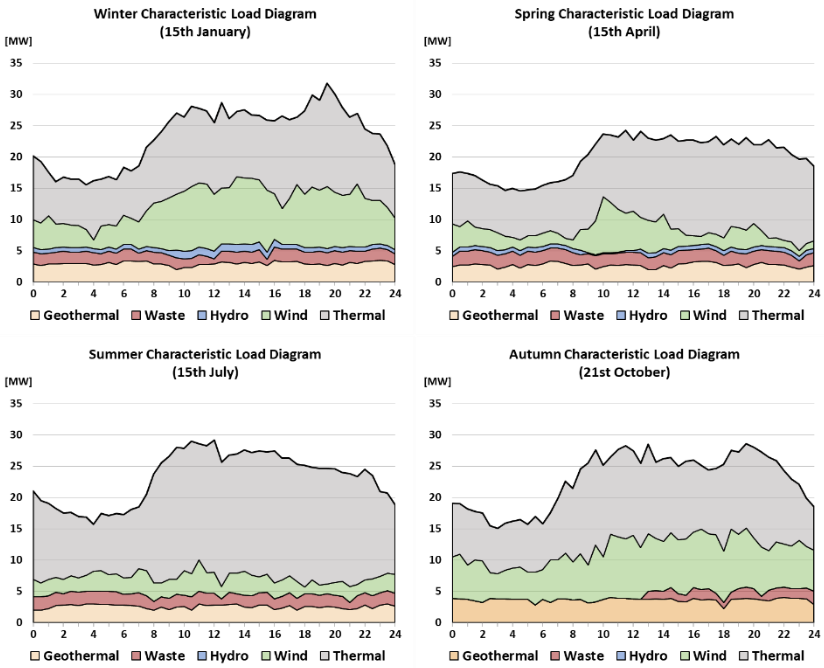

Figure 2 Terceira's characteristic load diagrams in each season

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

2.1.2 *Terceira's Electricity Grid Description*

The electric system of Terceira is composed of 8 power plants and 6 substations. It has a MV transmission line at 30 kV, MV distribution lines at 15 kV and LV distribution lines at 0.4 kV as displayed in Figure 3. The distribution grid has a total of 1490 km of network extension: 1092 aerial cables and 398 underground cables. 358 km correspond to 15 kV lines, 0.74 correspond to 30 kV while 1131 km are LV lines. On the other hand, the transmission grid has only 79 km of extension: 67 aerial and 12 underground cables.

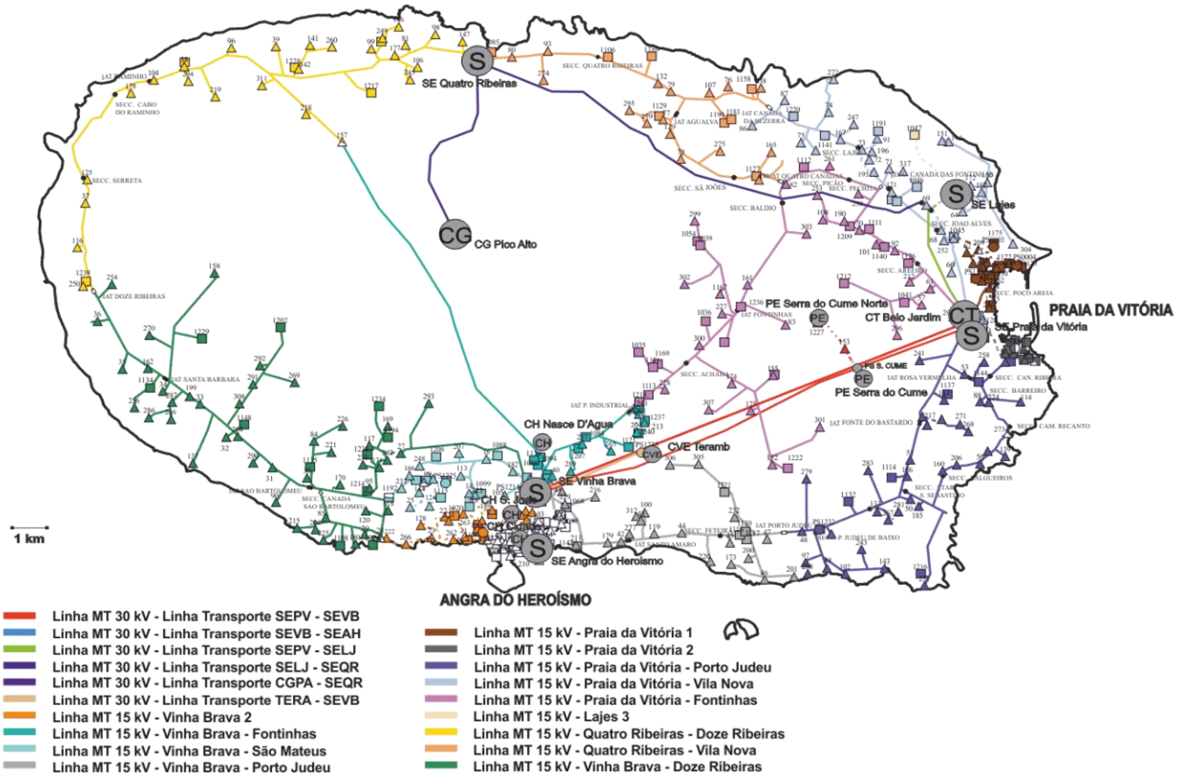

Figure 3 Terceira's Electricity Grid

The island has 79,5 MW of capacity installed with a diverse portfolio of power plants: thermal, hydro, wind, waste and geothermal. Hydropower plants are the oldest with more than 60 years and the geothermal power plant the newest, which is in operation only since 2017. The plant which generates more electricity is undoubtedly Belo Jardim power plant, followed by the geothermal plant Pico Alto and wind park Serra do Cume.

Table 1 shows the power plants existing in Terceira whose data will be used by the iVPP and thus will be subject to the integration tests. Table 2 presents the existing substations in Terceira.

Name	In operation since (*)	Type of production	Generator Groups			Electricity Production [MWh]
			Voltage level [kV]	Units	Instaled Capacity [kW]	
Belo Jardim	1983	Diesel Fuel	6,6	3	9 116	255,2
		Fueloil	6	6	49 000	120 029,8

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

Cidade	1955	Hydro	0,4	1	264	376,7
Nasce d'Água	1955	Hydro	0,4	1	720	852,1
São João de Deus	1955	Hydro	0,4	1	448	400,2
Serra do Cume	2008	Wind	0,4	10	9 000	23 192,5
Serra do Cume Norte	2012	Wind	0,4	4	3 600	7 555,8
TERAMB	2016	Waste	6	1	2 720	13 651,1
Pico Alto	2017	Geothermal	11	1	4 675	23 741,7
			-	28	79 543	190 055,2

* Date referring to the start of operation of the system and not including subsequent refurbishments or expansions.

Table 1 Terceira's Power Plants

Name	Abbreviation	In operation since (*)	Transformation Ratio	Installed Capacity [MVA]
Belo Jardim	SEBJ	1983	30/15 kV	10,00
Praia da Vitória	SEPV	2016	30/15 kV	20,00
Vinha Brava	SEVB	1990	30/15 kV	20,00
Angra do Heroísmo	SEAH	2003	30/15 kV	10,00
Quatro Ribeiras	SEQR	2010	30/15 kV	10,00
Lajes	SELJ	2004	30/6,9 kV	12,50
			30/15 kV	1,00
			Total	83,50

* Date referring to the start of operation of the system and not including subsequent refurbishments or expansions.

Table 2 Terceira's substations. Signalled in blue are the substations which will be subject to iVPP integration tests

As previously mentioned, the present deliverable will focus on the integration tests between the iVPP and the grid-assets of Terceira, involved in Use Case 2 of IANOS. The goal of this Use Case is to use supply-side assets to provide flexibility to the grid, minimize energy curtailment and avoid grid challenges. With this in mind, a description of the state and history of the power line is necessary.

Table 3 and Table 4 present the congestion history of Terceira's transmission and distribution lines.

Transmission Line	Voltage Level [kV]	Type	Conductor	Section [mm²]	Length [km]	R [Ω]	X [Ω]	B [Ω]	Thermal Capacity [MVA]	Max. Power [MVA]	Utilization Factor
Praia da Vitória - Vinha Brava 1	30	Aerial	ASTER	148	13,37	3,3145	4,8515	4,25E-05	16,11	10,14	63%

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

Praia da Vitória - Vinha Brava 1	30	Underground	LXHIOZ1	240	0,29	0,0462	0,0338	2,09E-05	20,47	10,14	50%
Praia da Vitória - Vinha Brava 1	30	Underground	LXHIOV	240	0,09	0,0145	0,0094	5,06E-06	21,82	10,14	46%
Praia da Vitória - Vinha Brava 2	30	Aerial	Cu	185	13,42	1,3531	0,5261	1,46E-06	28,06	8,03	29%
Praia da Vitória - Vinha Brava 2	30	Underground	XHIOV	240	0,25	0,0236	0,0027	2,03E-07	26,66	8,03	30%
Praia da Vitória - Serra do Cume	30	Aerial	ASTER	148	3,37	0,8368	1,2248	1,07E-05	16,11	6,87	43%
Praia da Vitória - Serra do Cume	30	Underground	LXHIOZ1	240	0,29	0,0459	0,0336	2,07E-05	20,47	6,87	34%
Praia da Vitória - Serra do Cume	30	Underground	LXHIOV	185	0,15	0,0370	0,0041	2,26E-07	18,39	6,87	37%
Vinha Brava - Serra do Cume	30	Aerial	ASTER	148	10,02	2,4852	3,6376	3,19E-05	16,11	12,29	76%
Vinha Brava - Serra do Cume	30	Underground	LXHIOV	185	0,14	0,0349	0,0038	2,13E-07	18,39	12,29	67%
Vinha Brava - Serra do Cume	30	Underground	LXHIOV	240	0,09	0,0142	0,0092	4,94E-06	21,82	12,29	56%
Praia da Vitória - Lajes	30	Aerial	ASTER	148	3,69	0,9156	1,3402	1,17E-05	16,11	5,09	32%
Praia da Vitória - Lajes	30	Underground	LXHIOZ1	240	0,44	0,0699	0,0511	3,16E-05	20,47	5,09	25%
Praia da Vitória - Lajes	30	Underground	LXHIOV	185	1,09	0,2644	0,0290	1,61E-06	18,39	5,09	28%
Lajes - Quatro Ribeiras	30	Aerial	Cu	95	14,15	2,9282	1,0621	3,35E-06	18,71	3,84	21%
Lajes - Quatro Ribeiras	30	Underground	LXHIOV	185	1,44	0,3479	0,1578	7,98E-05	18,39	3,84	21%
Lajes - Quatro Ribeiras	30	Underground	LXHIOV	240	0,07	0,0107	0,0069	3,72E-06	21,82	3,84	18%
Pico Alto - Quatro Ribeiras	30	Aerial	Cu	95	6,18	1,2793	0,4640	1,46E-06	18,71	4,44	24%
Pico Alto - Quatro Ribeiras	30	Underground	LXHIOZ1	240	0,08	0,0131	0,0096	5,92E-06	20,47	4,44	22%
Pico Alto - Quatro Ribeiras	30	Underground	XHIOZ1	185	0,18	0,0227	0,0198	1,13E-05	23,38	4,44	19%
Vinha Brava - Angra do Heroísmo 1	30	Underground	LXHIOV	185	2,43	0,5881	0,2667	1,35E-04	18,39	5,50	30%
Vinha Brava - Angra do Heroísmo 2	30	Underground	LXHIOV	185	2,41	0,5832	0,2645	1,34E-04	18,39	6,12	33%
Vinha Brava - TERAMB	30	Aerial	Cu	50	3,12	1,2540	1,1977	9,30E-06	12,47	3,07	25%
Vinha Brava - TERAMB	30	Underground	LXHIOZ1	120	0,45	0,1453	0,0586	3,23E-05	13,98	3,07	22%
Serra do Cume 4	30	Underground	LXHIOV	120	2,02	0,6517	0,2342	6,72E-05	14,81	3,70	25%
Total 30 kV					79,22						

Table 3 Terceira's Transmission lines congestion history

Substation	Distribution Line	Voltage Level [kV]	Peak Demand [kVA] (1)	Thermal Cap. Main Section [kVA] (2)	Utilization Factor [%] (1/2)	Voltage in the LV substation more unfavourable [pu] (3)	Capacity (*) [kVA] (4)	Available Power [kVA] (4-1)
SEPV	Praia da Vitória - Vila Nova	15	2 922	7 920	36,90%	0,950	5 776	2 854
	Praia da Vitória - Fontinhas	15	1 640	7 920	20,70%	0,950	2 788	1 148
	Praia da Vitória - Porto Judeu	15	2 848	7 920	35,96%	0,950	5 639	2 791
	Praia da Vitória 1	15	2 378	7 400	32,13%	1,001	6 457	4 079
	Praia da Vitória 2	15	2 085	5 460	38,18%	1,015	5 458	3 374
SEVB	Vinha Brava - Fontinhas	15	1 013	7 920	12,79%	0,989	4 933	3 920
	Vinha Brava - Porto Judeu	15	1 958	7 920	24,73%	0,950	4 468	2 509
	Vinha Brava - S. Mateus	15	2 140	6 990	30,61%	0,995	6 116	3 976
	Vinha Brava - Pronicol	15	2 030	6 990	29,04%	1,032	6 990	4 960
	Vinha Brava - Doze Ribeiras	15	3 099	7 400	41,88%	0,950	3 758	659
	Vinha Brava 1 (**)	15	0	10 910	(**)	(**)	(**)	(**)
	Vinha Brava 2	15	2 254	7 400	30,47%	0,959	7 272	5 017
	Vinha Brava 3	15	1 780	10 910	16,32%	1,035	10 910	9 130
SEAH	Angra do Heroísmo 1	15	153	6 990	2,19%	1,035	6 990	6 837
	Angra do Heroísmo 2	15	1 322	7 400	17,86%	1,029	4 102	2 780
	Angra do Heroísmo 3	15	1 100	3 380	32,54%	1,028	3 380	2 280
	Angra do Heroísmo 4	15	1 658	7 400	22,41%	1,017	4 702	3 044
	Angra do Heroísmo 5	15	1 661	10 240	16,22%	1,029	6 061	4 401
	Angra do Heroísmo 6	15	470	10 910	4,31%	1,027	3 643	3 173
SELJ	Lajes 3	15	398	5 460	7,29%	1,014	5 460	5 062
SEQR	Quatro Ribeiras - Vila Nova	15	1 288	7 920	16,26%	0,990	4 346	3 058
	Quatro Ribeiras - Doze Ribeiras	15	1 678	7 920	21,18%	0,950	3 304	1 626

(*) Capacity as a function for the voltage value at the most unfavourable LV substation and for the thermal capacity of the Output

Limitation by the thermal capacity of the main section if [(4) = (2)]

Limitation by the thermal capacity of an intermediate section with a smaller section than the main section if [(4) < (2)] e [(3) > 0,950]

Limitation by the voltage value in the most unfavourable LV substation if [(3) ≤ 0,950]

(**) Redundant output.

Table 4 Terceira's Distribution lines congestion history

In the case of a voltage or frequency event, the control system consists of each diesel generators connected to the grid in Belo Jardim Power Station, with conventional droop control methods implemented on individual speed and voltage regulators and based on droop characteristic.

Besides the indicated power generator units, also a Battery Energy Storage System (BESS) will be studied by the iVPP, and its data used for calculations. This BESS is based on lithium-ion batteries with a total capacity of 15MW / 10,5MWh by the end of life, and its commissioning will be concluded during 2022. This

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

equipment will be divided in 6 individual modules of inverters/transformers. The primary function of this BESS will be to replace spinning reserve from Belo Jardim Thermal Power Plant, allowing the growth of RES share in the electrical system, thus allowing to work the Belo Jardim Thermal Power Plant with only one electric generator. As for a secondary function the BESS will also be used for frequency and voltage regulation.

Table 5 includes information regarding the division of BESS capacity towards multiple ends such. Part of the batteries' capacity is used for spinning reserve, voltage and frequency regulation, while the rest can be used for the integration of renewable energies.

	Capacity [MW/MWh]
EoL Capacity	15 MW / 10.5 MWh
Capacity for spinning reserve	12 MW / 8 MWh
Capacity for Voltage and Frequency regulation	3 MW / 1.5MWh
Capacity for RES Integration	2 MW / 1 MWh

Table 5 Division of Battery Capacity towards ancillary services and others.

Furthermore, in the Azores archipelago and also specifically in Terceira Island, the population has access to different energy sale prices, according to the contracted power, tariffs used and voltage levels. The pricing conditions are express in the following tables. Table 6a includes the prices for the final MV client. Table 6b includes the prices for the final client in using LV bigger than 41,5kVA. Table 6c includes prices for the final client in the voltage between 20,7kVA and 41,5kVA. Table 6d includes prices for clients at LV smaller than 20,7kVA and finally Table 6e shows the prices for final clients using LV smaller than 6,9kVA

Sale tariff for final client in the Azores MV			PRICE
Fixed term			EUR/day
			0,0058
Contrated Power			EUR/(kW.day)
		Peak Power	0,1777
		Contracted Power	0,0338
Active Energy			EUR/kWh
	1st and 4th quarter	Peak hours	0,1359
		Full Hours	0,1159
		Off Peak Hours	0,0781
		Super Off peak	0,0715
	2nd and 3rd quarter	Peak hours	0,1307
		Full Hours	0,1116
		Off Peak Hours	0,0759
		Super Off peak	0,0738
Reactive Energy			EUR/kvarh
		Inductive	0,0250
		Capacitive	0,0188

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

Sale tariff for final client in the Azores LV>41,5kVA			PRICE
Fixed term			EUR/day
			0,1988
Contrated Power			EUR/(kW.day)
		Peak Power	0,5015
		Contracted Power	0,0435
Active Energy			EUR/kWh
	1st and 4th quarter	Peak hours	0,1570
		Full Hours	0,1380
		Off Peak Hours	0,0904
		Super Off peak	0,0807
	2nd and 3rd quarter	Peak hours	0,1565
		Full Hours	0,1363
		Off Peak Hours	0,0889
		Super Off peak	0,0818
Reactive Energy			EUR/kvarh
		Inductive	0,0311
		Capacitive	0,0237

Sale tariff for final client in the Azores 20,7kVA<LV<41,5kVA			PRICE
Contrated Power			EUR/day
	Tri-hour tarif	27,6	1,2732
		34,5	1,5838
		41,4	1,8945
Active Energy			EUR/kWh
	Tri-hour tarif	Peak hours	0,2956
		Full Hours	0,1587
		Off Peak Hours	0,0912

Sale tariff for final client in the Azores LV<20,7kVA			Price
Contrated Power			EUR/day
	Either Simple, Bi-hour or tri-hour tarifs	1,15	0,0720
		2,3	0,1299
		3,45	0,1734
		4,6	0,2262
		5,75	0,2762
		6,9	0,3282
		10,35	0,4823
		13,8	0,6364
		17,25	0,7886
		20,7	0,9499
Active Energy			EUR/kWh
	Simple Tarif		0,1636
	Bi-hour tarif	Peak Hours	0,1957
		Off Peak Hours	0,1047
	Tri-hour tarif	Peak hours	0,2361
		Full Hours	0,1697
		Off Peak Hours	0,1047

Social tarif for final client in the Azores LV<6,9kVA			Price
Contrated Power			EUR/day
	Either Simple, Bi-hour or tri-hour tarifs	1,15	0,0419
		2,3	0,0696
		3,45	0,0830
		4,6	0,1057
		5,75	0,1255
		6,9	0,1474
Active Energy			EUR/kWh
	Simple Tarif		0,1193
	Bi-hour tarif	Peak Hours	0,1514
		Off Peak Hours	0,0604
	Tri-hour tarif	Peak hours	0,1918
		Full Hours	0,1254
		Off Peak Hours	0,0604

Table 6 Sale tariff for final client in the Azores (MV, LV>41,5kVA and LV<41,5kVA).

2.2 Terceira testing case

This deliverable describes the methodology and results of the preliminary integration test conducted on the system of Terceira, regarding Use Case 2: Community supply-side optimal dispatch and intra-day services provision.

The preliminary integration test aims to test the performance of the System's Components that are used in each Use Case. Preliminary integration testing aims to bring together the different components (hardware or software) of a system and conduct a series of predefined tests to observe the system's response and its functionalities.

Use case 2 was selected to conduct the preliminary testing on, because it includes the major systems used in Terceira, namely the BESS, the Geothermal Plant, Wind Farms, the Waste incineration power plant and the PV farm. The primary objective of the Use Case for the first preliminary version of the integration presented in this documented is the optimal-day ahead energy dispatch utilizing BESS units in order to minimize costs and avoid RES curtailment of the power system operated by the EDA system administrator.

Because this deliverable concerns itself with the preliminary testing of the iVPP components, in Use Case 2 the components of the iVPP that are used are the Centralized Dispatcher (OptiMEMS), and the Forecasting Engine. The Forecasting Engine will perform Load, PV and Wind generation forecasting and OptiMEMS will perform the day-ahead scheduling and pricing.

2.3 Utilization of iVPP Components

The iVPP components, whose utilization is going to be further presented and analysed in this document, are the Forecasting Engine and the Centralized Dispatcher (CD), more specifically the optiMEMS tool. The optiMEMS tool is the core of the iVPP as it is responsible for making the decisions regarding the optimal dispatch of the available assets, while the Forecasting Engine is responsible to provide the CD with the necessary forecasts in order to make these decisions. In the following figure, the indicative workflow

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

between the Forecasting Engine, the optiMEMS and the Enterprise Service Bus (ESB) is presented, highlighting the data exchange between the different components and their processes.

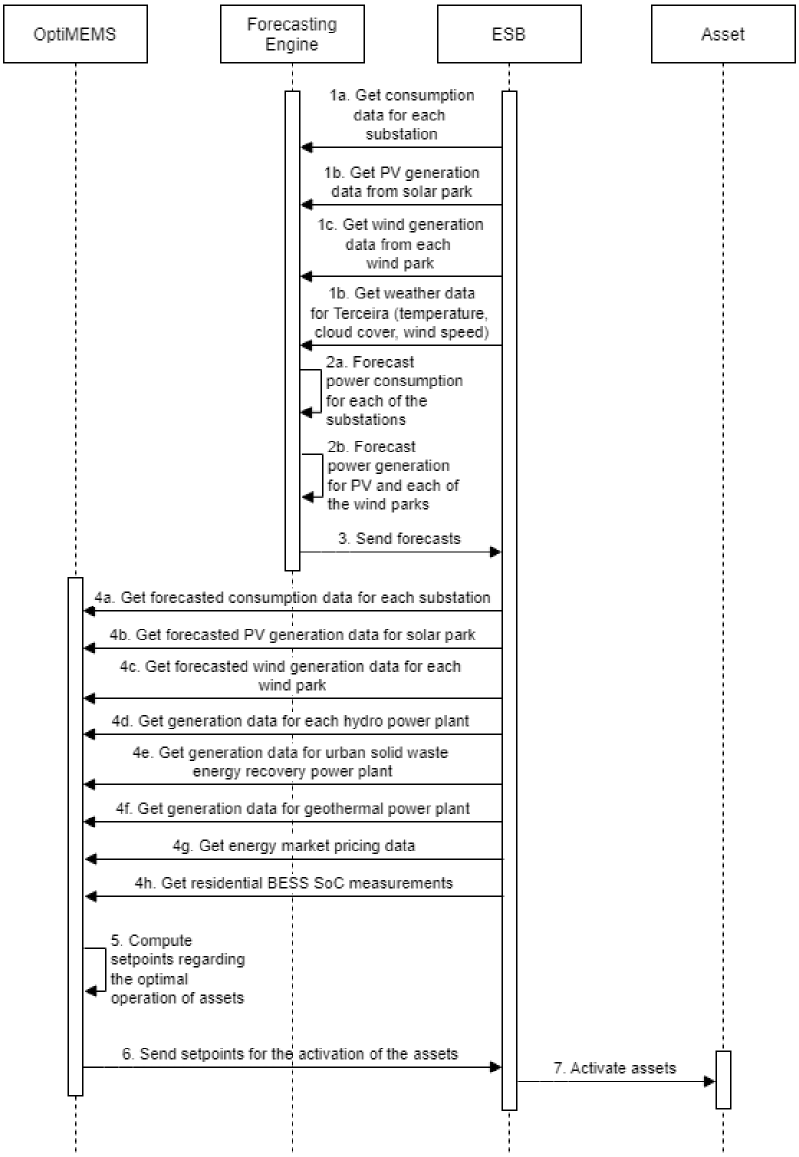

Figure 4 Workflow between the Forecasting Engine, the optiMEMs and the ESB

The first versions of the Forecasting Engine and the optiMEMS are presented in detail in the documents *D4.3 - iVPP Forecasting Engine v1.0* and *D4.7 - The iVPP Centralized Dispatcher*, respectively. In the following chapters, an introduction to utilization of these components within IANOS project is going to be provided.

2.3.1 Forecasting Engine

As mentioned previously, the forecasting engine will produce the necessary inputs for the decision support system, assisting in the best scheduling and management of the grid assets. The latter is going to be achieved by developing forecasting algorithms for energy generation, from solar and wind parks, and energy consumption.

The forecasting of the energy-based time series was done using a variety of machine learning models, including tree-based models and SVM, deep learning models (RNN, LSTM), physical models, and ensembles. The approach mainly depends on the machine learning methodology's feature engineering component, which makes use of history values, temporal characteristics, and weather features. The forecasting engine will be able to provide both day ahead and intraday forecasts, with a customizable resolution that can vary from 15 minutes to 1 hour.

It has been proven through validation that the suggested lightweight, feature-dependent methodology generates highly precise forecasts with a minimum of training data and time. The *D4.3 - iVPP Forecasting Engine* presents in detail the methodology used in the development of the Forecasting Engine as well as the results in terms of accuracy and execution time of the models.

In the context of UC2 for Terceira, the Forecasting Engine provides the Centralized Dispatcher (CD) with forecasts for the consumption for each of the six substations and wind generation forecasts for the two wind power plants (PESC - 9 MW and PESN - 3,6 MW). Furthermore, an analytical model has been developed to estimate the expected generation of the planned 2MWe PV power plant, where the PV power output is based on equations derived from the photoelectric effect and weather conditions.

2.3.2 OptiMEMS

OptiMEMS refers to the decision tool developed by CERTH to maintain the grid's power balance, optimize the self-consumption, and provide grid services in times of emergency aside from scheduling the small and large-scale assets of the grid optimally. Advanced energy management techniques are utilized in multi-source network power systems, which are monitored by OptiMEMS. The tool's primary goal is to reduce daily costs overall by maximizing the flexibility of the energy portfolio and identifying the ideal set points for supply, demand, and storage.

In its standalone format, OptiMEMS currently consists of three main sub-components: an optimization engine that generates the optimal schedule for the following day by meeting load demand in each time slot; a forecasting tool for the prediction of future consumption and generation for grid's assets; and a real-time tool that verifies potential deviations between the measured data and the schedule for the day ahead.-In the context of the IANOS project, and more specifically for the preliminary testing of the iVPP components for the UC2 that is presented in the current document, the OptiMEMS will make use of only the first sub-component, namely the optimization engine, while the forecasting functionalities will be provided to the OptiMEMS by the IANOS Forecasting Engine.

The Enterprise Service Bus (ESB) of the IANOS project is used by OptiMEMS to get the necessary forecasts for solar, wind generation and energy consumption produced from the Forecasting Engine in order to provide the optimal dispatch schedule for the involved energy assets, that is stored in the ESB.

3 Testing methodology and results

3.1 Testing Methodology

One of the most important steps in the implementation of a software and hardware process is the iterative testing. More specifically, when a component of a system is implemented, it is imperative to apply tests in order to check whether the implementation is sound and robust, that the component's individual functional and non-functional requirements have been satisfied, what is the component's operation when it is interconnected with other components of the system, and how the whole system functions given certain testing scenarios. In this section the tests that the optiMEMS and Forecasting Engine components went through, in order to ensure their appropriate functions, are presented.

3.1.1 Unit Testing

The unit testing tries to assess the core components of a software package. This sort of testing, which involves testing individual classes or small groups of classes, is often carried out by developers (a package). Prior to integrating these parts of the code (packages) into the rest of the system, it seeks to assure high quality in the design and implementation of classes by ensuring that they operate as expected and checking for "bugs" in the code. Especially in commercial and industrial applications, early detection of "bugs" is much more cost-effective than later stages, and it also guarantees that the delivered component will be stable and resource-efficient during daily operations. Unit testing frequently looks at metrics like test/code coverage, cyclomatic complexity, code duplications, rules compliance, comment coverage and other information relating to code.

The majority of programming languages come with their own frameworks for unit testing. The test team will decide on the best tool during the construction of the test plan based on the testing requirements for each individual feature.

3.1.2 Functional testing

This test's primary goal is to validate that the component performs in accordance with the relevant function technical requirements that were defined throughout the design process. The test component is examined as a standalone module, in order to assess its expected functionalities and finally is included in the system after completing successfully the functional test.

The main functionalities and behaviour of the component are the focus of the functional tests, which are not based on a specific testing process but rather on ad-hoc test cases. The test cases are defined from the technical requirements (D2.1) and architecture (D2.13) delivered earlier in the project's lifecycle. As a result, a set of test cases has been identified for each component and is currently being partially conducted in order to evaluate the expected functionalities, as well as discover any restrictions, performance difficulties, and other associated metrics that can guarantee the right functional behaviour.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

3.2 Preliminary integration results

3.2.1 *Forecasting Engine*

3.2.1.1 Unit Testing

In the unit test process, the Pytest module was utilized to assess the Forecasting Engine. The main focus of the test components was on the proper connections with other components of the system for data retrieval (e.g., Enterprise Service Bus), the correct processing and filling in of data in the event of missing data, and lastly the forecast performance.

3.2.1.2 Functional Testing

No	Test	Description	Evaluation criteria	Results
FE-FT-1	Data pre-processing	Handle properly the missing data and outliers	When there are data gaps or outliers, the Forecasting Engine still produces accurate load forecasting results. An explanatory message is returned if the input is completely empty	Pass
FE-FT-2	Customized forecast resolution	The Forecasting Engine can produce outputs with multiple time resolutions, which are specified at the beginning of the training	Verify whether the output of the Forecasting Engine is feasible for time periods of 15 and 60 minutes	Pass
FE-FT-3	Provision of various types of forecasts	The Forecasting Engine provides forecasts of different energy assets	Provide forecasts for the involved load assets	Pass
			Provide forecasts for the involved RES assets	Pass
FE-FT-4	DA and ID forecast horizon	The Forecasting Engine provides a day-ahead and a complementary intra-day forecast to update the results of the day ahead	Check if the intraday forecast improves the results of the day ahead forecast module	Pass
FE-FT-5	Model retraining	The models of the Forecasting Engine are saved and reloaded. The models can be retrained	The models can be saved, reloaded and retrained in all test cases.	Pass

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

		depending on the most recent data after a fixed period of time		
FE-FT-6	Data retrieval	Data that are saved in different forms can be loaded by the forecasting engine	The tool can load data from various types of inputs (e.g., JSON, CSV, xlsx).	Pass
FE-FT-7	Forecasting accuracy performance	Assess the accuracy of real-time measurements under various conditions	Accuracy of the Forecasting Engine is based on error metrics such as SMAPE, MMR, and RMSE.	Pass
FE-FT-7	Forecasting execution performance	Assess execution time performance under various conditions	Low execution time during the real-time forecasting (under 10'')	Pass

Figure 5 Results for the Functional Testing of the Forecasting Engine

3.2.2 *OptiMEMS*

3.2.2.1 Unit Testing

The Optimal Dispatch module (OptiMEMS) has been tested as a standalone unit to verify its resilience against all potential stressing conditions. OptiMEMS has undergone a number of tests to make sure it won't collapse either isolated or in an error-propagating way because of its heavy dependence on various input signals and configuration.

3.2.2.2 Functional Testing

No	Test	Description	Evaluation criteria	Results
OM-FT-1	Setpoint estimation of the optimal dispatch scheduling	Provide the optimal energy day ahead dispatch schedule in the form of setpoints.	Generate a feasible solution and store it in the appropriate format	Pass
OM-FT-2	Infeasible solution	OptiMEMS must notify the operator when an optimal solution cannot be found	The tool must inform with a failure message	Pass

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

No	Test	Description	Evaluation criteria	Results
OM-FT-3	Handle missing data	The OptiMEMS module requires multiple inputs (load, generation forecasts etc.). If any of these are missing, the OptiMEMS module will be unable to determine the optimal scheduling.	In a case of missing inputs, the Optimal Dispatch module should be terminated smoothly and inform with a failure message	Pass
OM-FT-4	Handle incorrectly formatted inputs	The inputs to the OptiMEMS module must be in a specific format. If any of these do not follow the format specified, the OptiMEMS module will be unable to determine the optimal scheduling.	In a case of missing inputs, the Optimal Dispatch module should be terminated smoothly and inform with a failure message	Pass
OM-FT-5	Optimization execution performance	The OptiMEMS module should provide results in a reasonable amount of time	The optimization results are obtained in less that 10 minutes	Pass

Figure 6 Results for the Functional Testing of the optiMEMS

3.2.3 *Preliminary integration results of the optimization process for UC2*

In this chapter, the methodology followed and the final results of the process regarding the optimization of the ESS assets that are involved in UC2 are going to be presented. As mentioned previously, the OptiMEMS module will be responsible as the core module of the Centralized Dispatcher for the completion of this particular task. The component will receive as inputs the forecasted generation for available RES assets and the respective load profiles from the substations and ultimately will produce the optimized setpoints for the dispatch of the BESS units. Additionally, the constraints used for the optimization process are going to be defined and taken into account by the OptiMEMS module.

The units that were used in the optimization process can be divided into two categories: demand units and generation units. The considered aggregated demand in the Terceira Island is the one provided by the 5 major substations located in the island. Regarding the generation units, these have been already mentioned in the previous sections (8 electricity producing facilities - Thermal Power Plant at Belo Jardim (CTBJ) with a capacity of 58.1MWe, Wind farm on Serra do Cume (PESC - 9 MW), Wind farm at Serra do Cume Norte (PESN - 3,6 MW), Urban Solid Waste Energy Recovery Power Plant CVE TERAMB - 2,6 MW), Geothermal power plant in Pico Alto (CGPA - 3,5 MW) and 3 hydroelectric power plants with a combined 1,4 MW, in Cidade (CHCD), Nasce D"gua (CHNA), and So Joo (CHSJ)).

The purpose of the study is to evaluate the optimal dispatch schedule of the 10.5 MWh BESS (day-ahead horizon) with the objective to reduce the grid's overall operating costs (at this stage, we have considered that the main system costs are allocated to the thermal -diesel- plant operation). In conjunction to the system costs considerations, the algorithm will select BESS activation depending on the energy excess or shortage (RES generation exceeds demand or the opposite, respectively), being utilized as storage unit (charging) or supplementary unit to cover the remaining demand (discharging). The problem has been instantiated by using explicit constraints for the major technical and economic parameters of the system: First and foremost, system supply and demand balance should be achieved at all times, taking into account the islanded network of Terceira. Then, the BESS charge-discharge limit has been set to 10-90% to avoid battery degradation, while the C-rate was set to 0.5 during charging and to 1 during discharging. In all cases, the starting level of SoC is 80% and must remain within operating limits in stored energy and amount of energy discharged/charged. The diesel unit is considered as a base ('grid forming') unit with a total nominal power of 45 MW and different pricing in the 4 operating load areas:

- 0-25%, 0.27 €/kWh
- 25-50%, 0.23 €/kWh
- 50-75%, 0.22 €/kWh
- 75-100%, 0.22 €/kWh.

The aforementioned values have been evaluated based on the typical fuel consumption of the generators in the studied power plant at different load factors, in alignment with the current fuel market prices, as of August 2022. The plant, as a base unit, is considered to be operational at all times and has a minimum operating power of 6.96 MW. Finally, solar and wind generation units are curtailable, i.e. their power is reduced if the resulted energy cannot be consumed by the system or stored in the battery.

The figures below show the optimization results for 4 days, each one corresponding in a different season. In each case, the 1st graph depicts the resulting setpoints for the BESS charging and discharging intervals, as well as its respective current state of charge (SoC). The 2nd graph depicts the respective day's

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

total load generation and load consumption. The diesel unit's generation, as a base unit is also illustrated. The functionality of the algorithm is successfully tested, through close inspection of the results; the charging intervals correspond to the intervals when production exceeded the total load consumption. BESS SoC slope is affected by the considered C-rate value, as mentioned above. The optimization ensures that excess energy generation is stored into the ESS, in order cover part of the demand in low production periods and reduce the contribution of the thermal power plant overall.

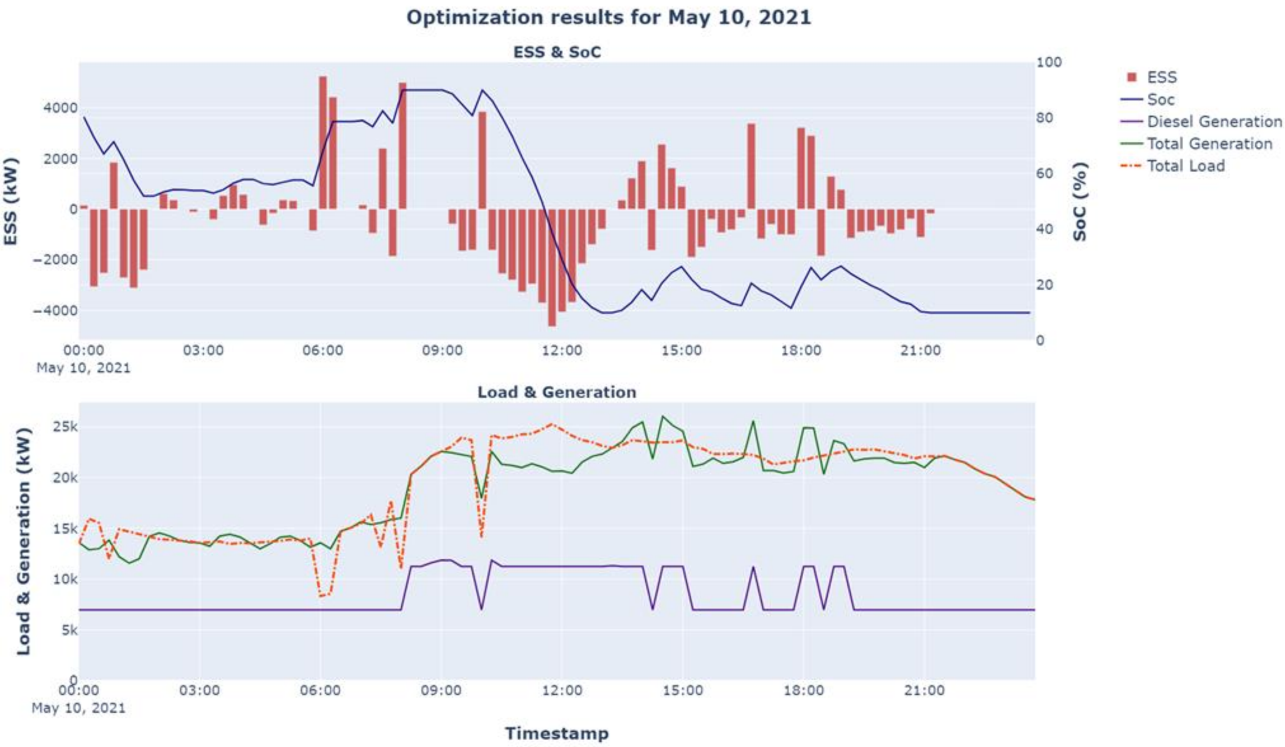

Figure 7 Optimization results for the usage of the BESS in May according to the iVPP setpoints

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

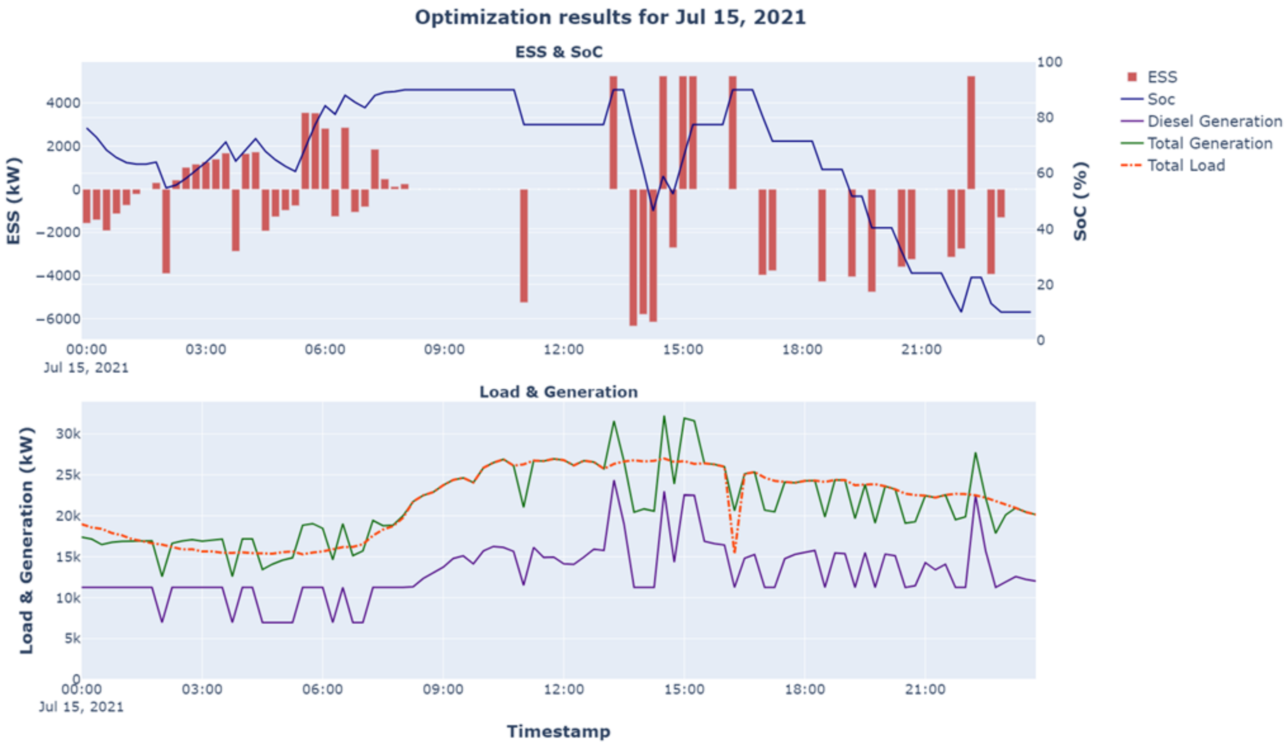

Figure 8 Optimization results for the usage of the BESS in July according to the iVPP setpoints

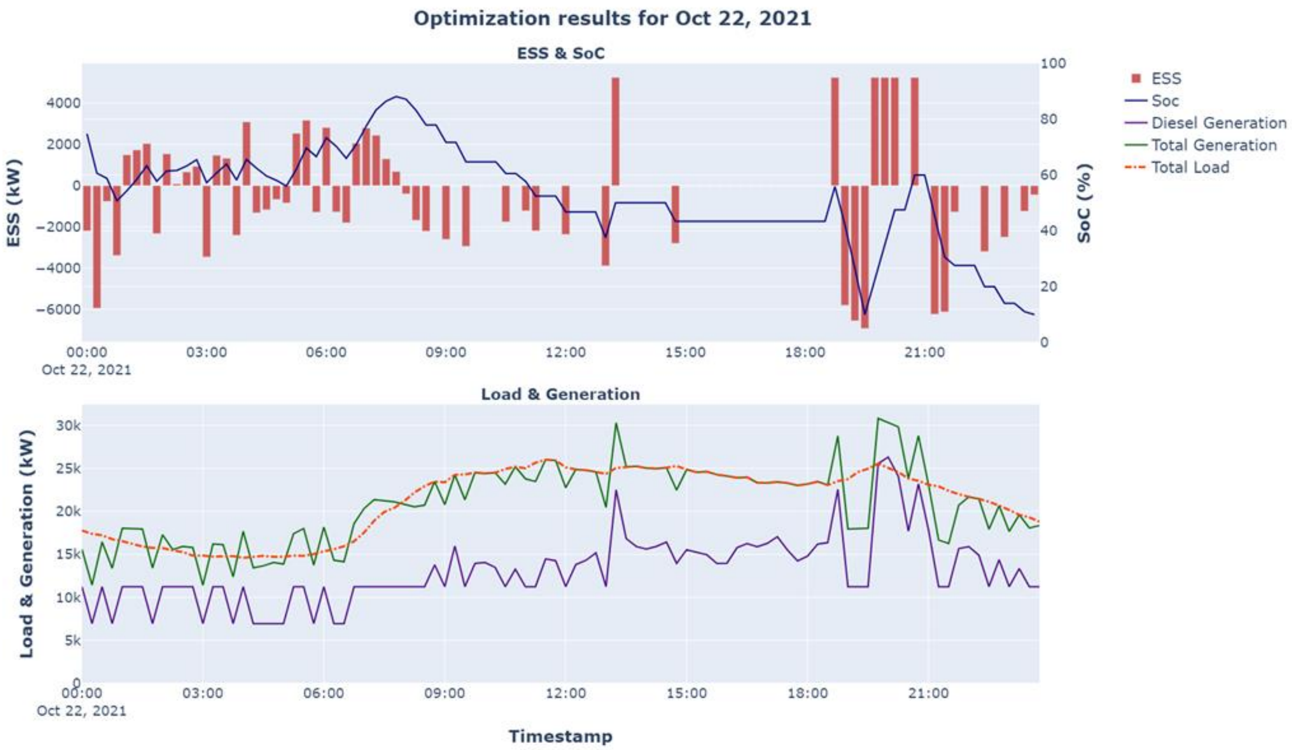

Figure 9 Optimization results for the usage of the BESS in October according to the iVPP setpoints

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

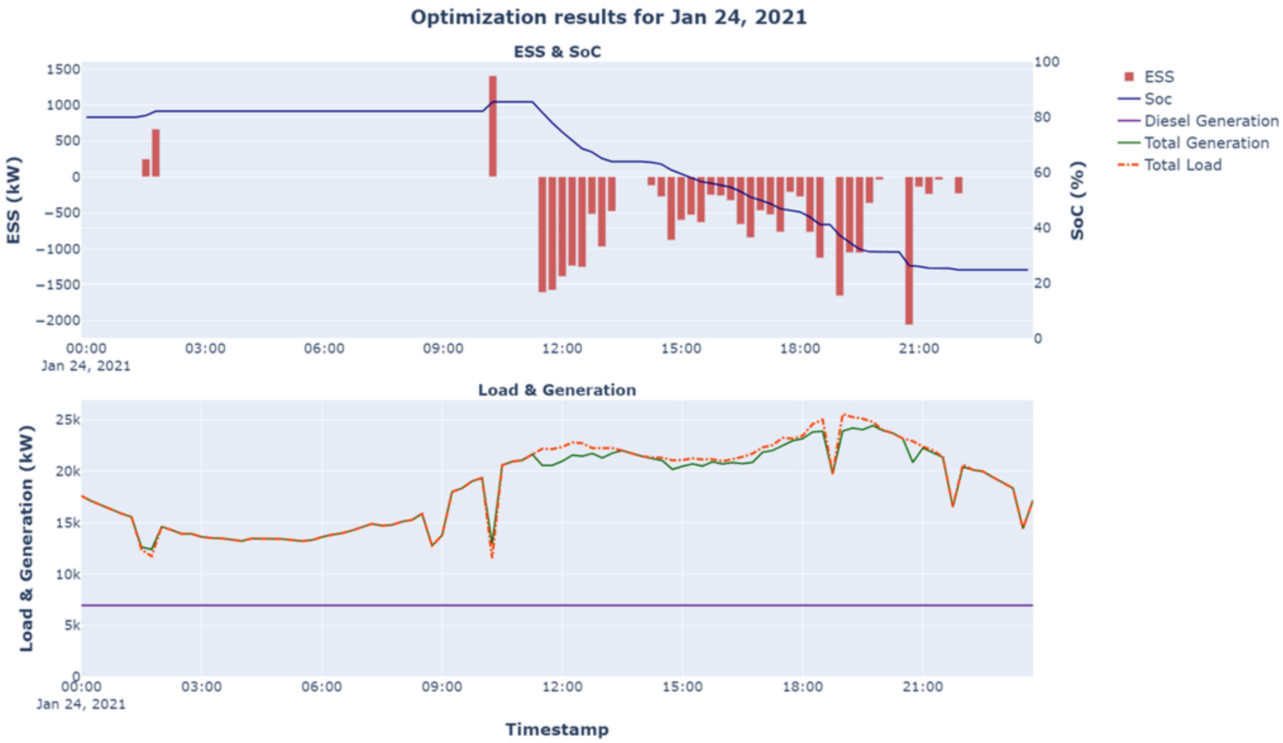

Figure 10 Optimization results for the usage of the BESS in January according to the iVPP setpoints

It is important to understand the cost-benefit for the system by optimally dispatching the BESS through the day ahead horizon, as the main objective of the algorithm. The following figure depicts the overall costs of the system operation with and without the optimization process. The graph clearly demonstrates that after the OptiMEMS module has defined the appropriate setpoints, the overall operational costs (referred to the thermal power plant) for each day examined are lower. More specifically, the cost reduction stood at approximately 4.7 % in summer and autumn days, when total energy generation was higher, while it resulted close to 3% in winter and spring days.

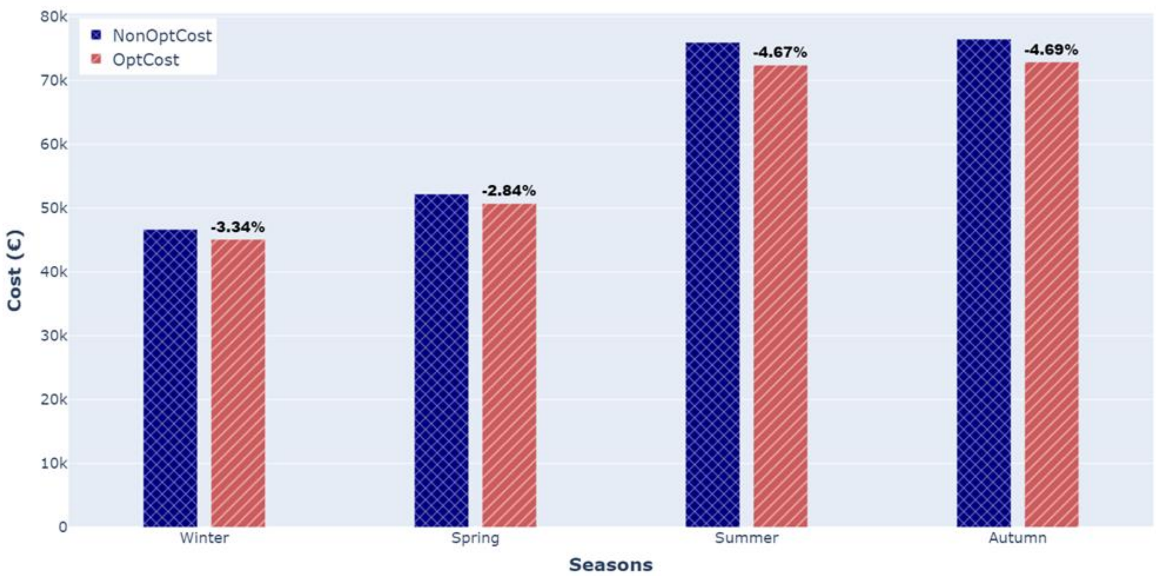

Figure 11 Costs of the system operation with and without optimization by the iVPP

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

4. Upcoming Testing Plans

The IANOS architecture's different components are scheduled to continue to develop as the overall integration is progressing and the pilot deployment gets underway. Thus, in order to ensure that all the additional functionalities, derived from the further expansion of the individual components, are adequately reported, it becomes evident that testing and its documentation must be expanded. For that purpose, several future testing plans have been scheduled to ensure that the is system operated based on the specified requirements.

In the current deliverable, the main focus was to describe the methodology that was followed in the testing of two of the main components of the iVPP, them being OptiMEMS and Forecasting Engine. Following their development, the rest of iVPP components need to be similarly tested and validated, on top of actual pilot data. In the future, the main aims would be:

i) to achieve the fully-grown integration of Terceira system's data into the iVPP (establishing all connections and ESB endpoints needed);

ii) to present an upgraded methodology and detailed algorithmic process, that will update the current optimization results, using more detailed data about the energy assets on the island;

iii) to include the BESS potential for intraday balancing services supply into the algorithm, by introducing relevant frequency and voltage capacity reserves;

iv) to lay out, examine and decide on other, relevant options to be considered for the next version of OptiMEMS functionalities (e.g. to consider detailed cost functions of the diesel plant unit(s) -that may include elements such as start-up costs, constraints regarding the total plants cycles per hr. etc.-, consider different relevant objectives to examine: minimize RES curtailment; minimize diesel unit participation (minimize CO2) etc.);

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

5. Conclusions

Report D6.3 provides the state of the integration of the iVPP with grid-assets participating in Use Case 2 of the project IANOS, in Terceira. To inform on this integration, this deliverable presents the methodology used in the preliminary tests on the integrability of these assets and specific iVPP components. With this intent, the report describes the methodology that should be employed on the iVPP decision making to determine whether function and non-functional requirements have been met. More specifically, unit and functional testing were performed on the Forecasting Engine and the OptiMEMS components, as these two components comprise the entire decision-making system. Aside from testing, the integration results, along with their respective plots, are also provided, taking into account the existing assets in Terceira.

In the future, an examination of the development and integration details of all Terceira components will be needed, as well as their communication specifications, based on the methodology presented.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810