Generalized Operational FLEXibility for Integrating
Renewables in the Distribution Grid (GOFLEX)

D7.4 Report on Demonstration Results Evaluation – Use Case 1

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Executive Summary

The report at hand is the final deliverable of WP7, System Deployment and Evaluation – Use Case 1, aiming to report spherically the results of the GOFLEX pilot implementations at Cyprus.

In this scope, the report elaborates on the achievements not only at technical level but also extracts great lessons learnt for the DSO and from GOFLEX users experience throughout the pilot action. Even more significant are the business analyses derived from tangible parameters for the DSO and the university as a microgrid operator/energy community.

At technical level, the Cyprus pilot has achieved most of the installation scale targets, despite the technical challenges faced during the course of the project. Focused contingency actions and timely interventions made most of the scaling targets possible. Performance-wise the demo site has reported targeted Key Performance Indicators through specified metrics either tracked at platform level (trackable), or derived from various pilot metrics (non-trackable). Furthermore, business metrics that are related to the business services developed within the GOFLEX platform for the pilot partners, are also reported. Overall performance is assessed as fulfilling taken into account the complexity of developed technologies and solutions. Business analyses outcomes are also promising for the DSO and university, towards their transition in the new energy era.

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List of Acronyms and Abbreviations

Abbreviation	Definition
BRP	Balancing Responsible Party
CA	Consortium Agreement
CDEMS	Charging-Discharging Energy Management System
CEMS	Charging Energy Management System
DSL	Digital Subscriber Line
DOMS	Distribution Observability and Management System
DSO	Distribution System Operator
EMS	Energy Management System
FMAN	Flexibility Manager Operator
FMAR	Flexibility Market Operator
FOA	FlexOffer Agent
GA	Grant Agreement
HEMS	Home Energy Management System
MGRP	Microgrid Responsible Party
MV	Medium Voltage
OCPP	Open Charge Point Protocol
PLC	Power Line Communications
SAT	Site Acceptance Test
SCADA	Supervisory Control And Data Acquisition Data Acquisition
SP	Service Platform
SRA	Scalability and Replicability Analysis
UCY	University of Cyprus

1 Introduction

1.1 Purpose

The current deliverable is the fourth deliverable of WP7 and aims to report the results of the demonstrated use cases in Cyprus demo site.

1.2 Document Structure

The remaining Section 1 overviews the GOFLEX platform and describes the business use cases that have been demonstrated in Cyprus.

Section 2 is elaborating on the DSO's experience throughout the project, analysing first the state of play at project closure and then denoting the most important lessons learnt.

Section 3 is providing the prosumers' experience from the project, taking provision to include the UCY microgrid as an energy community/microgrid end-user.

Section 4 is providing an evaluation of the demonstrators performance through KPIs, and includes the methodology for each KPI, as well the figures achieved, that yields to an overall assessment of the pilot actions.

Section 5 is elaborating on the CBA for both the DSO and the UCY microgrid.

1.3 GOFLEX System

The GOFLEX system implements an end-to-end flexibility platform enabling and integrating all pertinent market players. In GOFLEX, end users of energy place offers to sell or activate discrete amounts of energy flexibility on a market. In the project demonstrations, the distribution system operator (DSO) is the procurer of flexibility by submitting a buy-offer to the market. Technology is also provided to the DSO to automate and optimize use of flexibility in the grid.

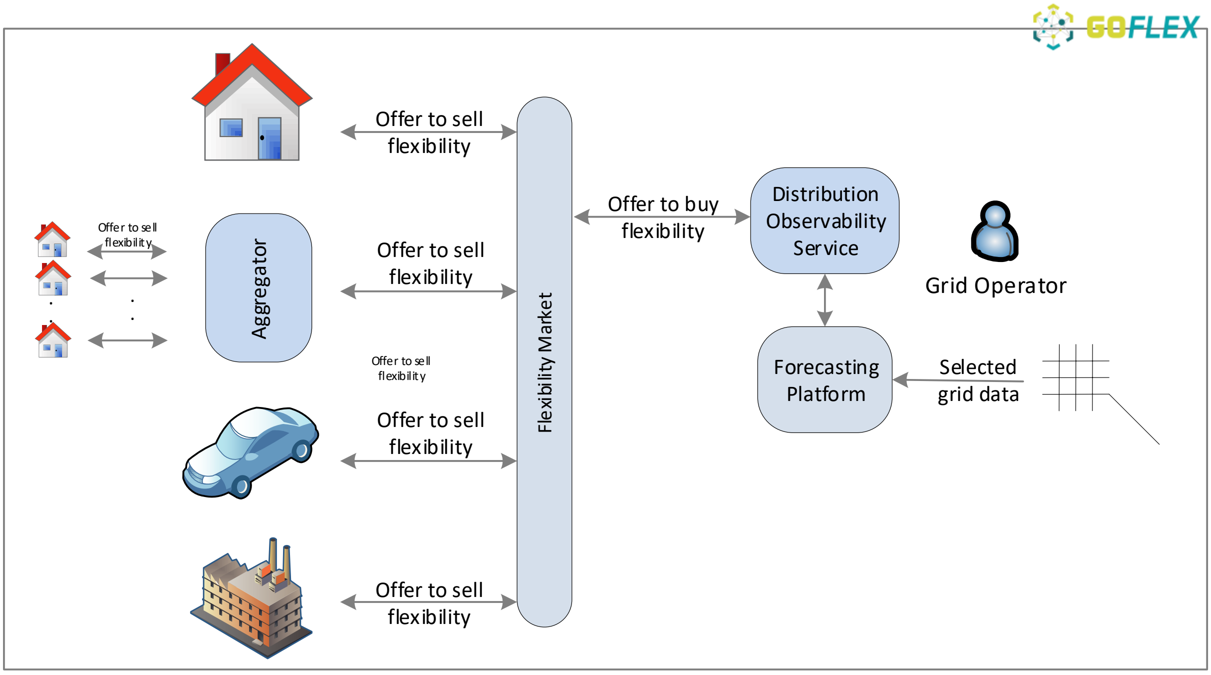


Figure 1: Illustration of GOFLEX Concept

Carrying out automatic trading of energy flexibility requires an integrated suite of technological components. Working from the bottom upwards, energy users such as factories, homes, and electric vehicles each require a suitable energy management system to physically control the energy loads that deliver flexibility. Thus a Factory Energy Management System (FEMS) controls factories and commercial buildings; a Home Energy Management System (HEMS) controls residential locations; a Charging Energy Management System (CEMS) controls electric vehicle charging stations; a Charging/Discharging Energy Management System (CDEMS) controls an electric vehicle capable of discharging to the grid. Other types of energy management system such as smart plugs or direct controls are also used. The energy management systems communicate available flexibility to a FlexOffer Agent (FOA). The role of the FOA is to transform information on available flexibility into a standard format and provide it to a centralized Flexibility Manager Operator (FMAN). The FMAN aggregates the offered flexibility according to predefined criteria and places the offer on a Flexibility Market Operator (FMAR) and receives notifications about whether the offer is accepted. When an offer is contracted, the FMAN notifies the energy management system via the FOA. Collectively, the FMAR, FMAN, and FOA comprise an automatic trading platform (ATP). The DSO accesses energy flexibility by trading on the market. From the DSO side, a Distribution Observability and Management System (DOMS) receives grid data and forecasts from the Service Platform (SP). DOMS then optimizes where and when flexibility is needed to meet operational needs. The required flexibility is expressed as a buy-offer and sent to the trading platform. Figure 2 summarizes the technological components of GOFLEX systems.

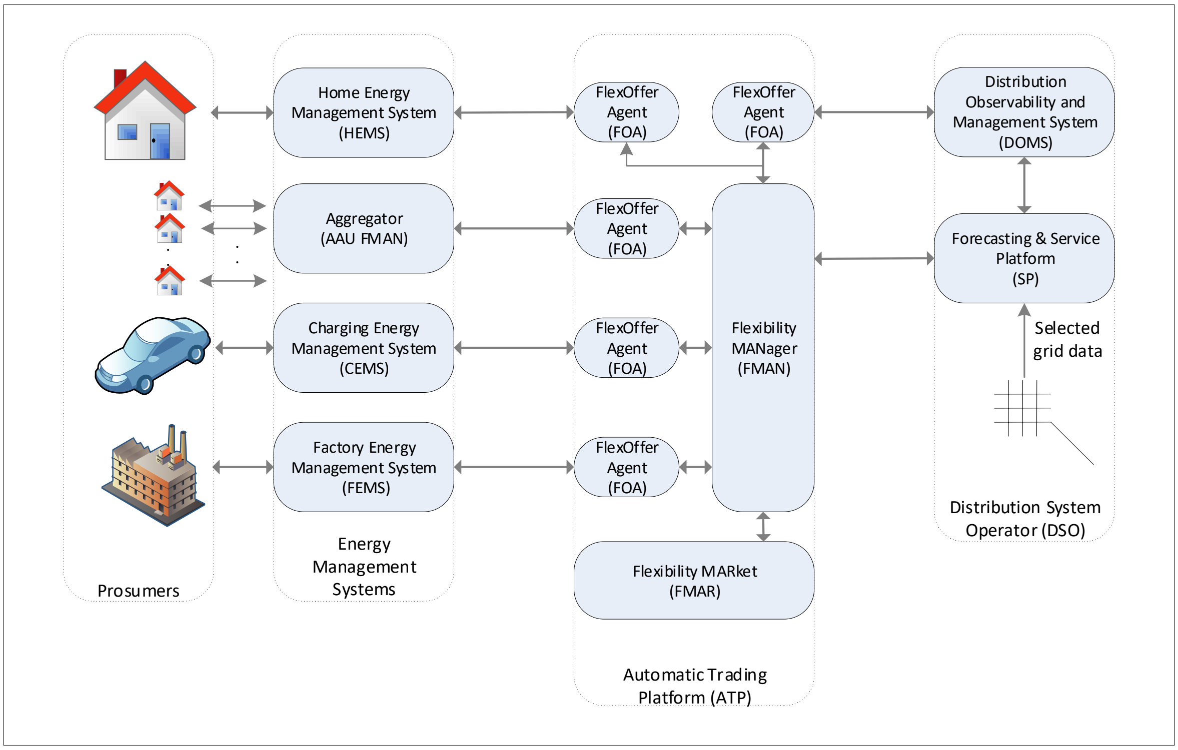


Figure 2: GOFLEX System Components

1.4 Business Summary for Demo Site 1

The Cyprus demonstration site examines two different use cases. The first use case concerns the microgrid within the campus of University of Cyprus (UCY), while the second one concerns dispersed prosumers within the Cyprus island.

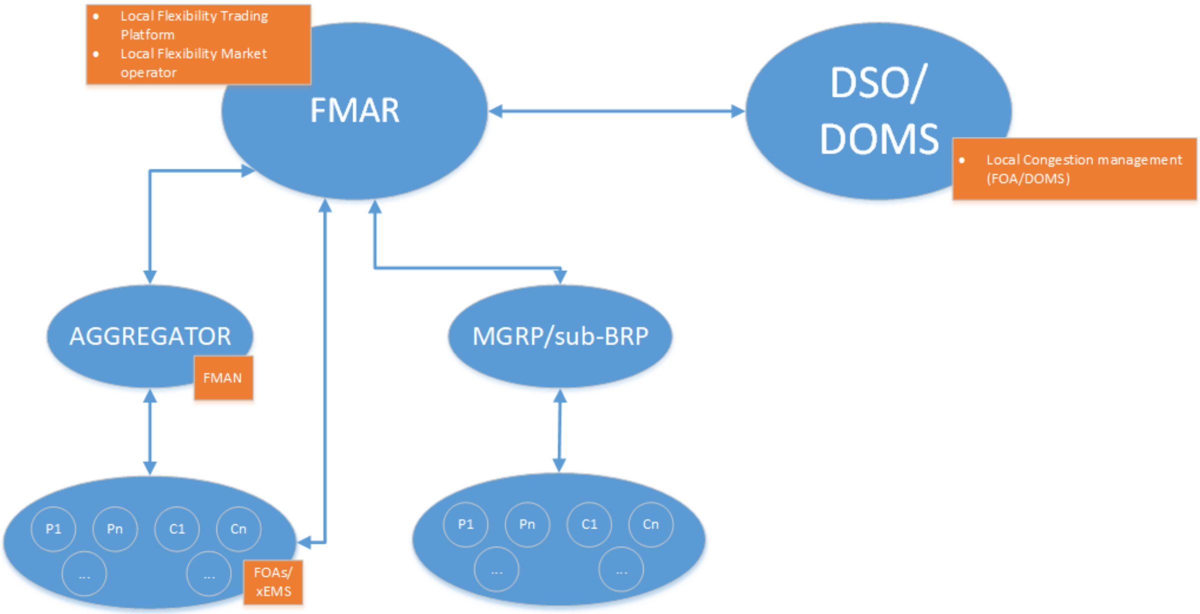


Figure 3 Use cases diagram at Cyprus demo site

1.4.1 Demonstration Case 1B: Local Congestion management

As depicted in Figure 3, the DSO utilizes the DOMS to assess the grid's state and upon a violation of a threshold parameter, issues a buy-offer to the FMAR through its FOA. FMAR is trying to trade the buy-offer with the flexibility offer pool from the end-users, either directly trading or delegated through an aggregator. Trading is subject to technical, financial, and geographical criteria. Once the buy-offer is successfully traded, FMAR issues flexibility schedules towards the pertinent end-users to mitigate the congestion at local level.

The business case for the DSO is avoided costs of grid reinforcement/expansion and or curtailment penalties Vs Flexible Energy + Operational Costs + Energy Transfer Cost (where applicable).

Congestion management also includes a voltage rise at an LV feeder end due to excessive PV production and consequent reverse flows.

The Cost-Benefit Analysis for Demonstration Case 1B is developed in §6.

1.4.2 Demonstration Case 1A: University Microgrid management

Also illustrated in Figure 3, the university microgrid plays the role of an aggregator, sub-BRP (Balancing Responsible Party) that one hand optimizes internally its resources and in addition offers any residual flexibility to the market.

UCY has integrated 4 BEMSes in a centralized energy management system, which enables the university to act a MGRP (Microgrid Responsible Party) and maximise its self-consumption / minimize energy cost, as well as dynamically match its energy demand against the grid's available capacity. Furthermore, UCY is acting as the local BRP/sub-BRP of the microgrid utilizing residual flexibility to trade on the market according to the needs of the DSO.

The business case for the UCY is optimizing its portfolio of energy carrying media and gain extra profit for trading residual flexibility.

The Cost-Benefit Analysis for Demonstration Case 1A is developed also in §5.

1.5 Related Documents

This document is related to the similar deliverables of the other demonstration sites of the project, namely D8.4 and D9.4. It is also directly related to Deliverables D7.1, D7.2 and D7.3 of WP7.

2 DSO Experience

2.1 Current state of play:

EAC(DSO) is a newly established system operator after the recent abidance to the European directives, accompanied by the financial and operational unbundling of operations, under the single vertical EAC business. The distribution activity is however somewhat differently structured than the European standard practice. EAC(DSO) remains within the same public-owned vertical business but is separately managed from distribution grid development and maintenance, named Distribution System Owner (DSOw). DSO owns no assets; DSOw is the whole distribution asset owner. Adding to this, is the fact that EAC(DSO) is the only DSO in Cyprus, a still isolated island system with no primary energy sources.

Cyprus is still struggling to operate the electricity market, with TSO being the allocated market operator. The market operation is postponed due to delays in the procurement procedures for the operator platform. A pseudo-market has been decided by the Regulator as a transition market to lead to the full electricity market operation, based on bilateral supplier-producer contracts that are cleared on a monthly basis. The transition marker does not include a centrally managed forward market, neither day-ahead, intra-day, balancing, or ancillary services markets.

However, RES penetration is pursued through various policy schemes that, for the moment, achieve EU’s 2020 goals. No storage has been integrated into the grid yet, apart from some minor pilot installations. A regulatory framework is only currently developed for grid/community storage only. Grid monitoring is under a roadmap implementation with a distribution SCADA and advanced metering infrastructure. Also, demand response is only currently being incorporated into the market rules, but at an infancy level. Retail tariffs have been mostly flat, with Time-of-Use tariffs applied with no major impact on demand side shaping. No explicit or dynamic retail tariffs have been applied. The DSO’s business is based on grid fees and is regulated. In addition, TSO-DSO coordination in a conventional level. Nevertheless, DSO is expected to fulfill all European directives under the abovementioned, slow pace evolving environment.

2.2 Lessons learnt from GOFLEX:

GOFLEX has been a great adventure for the Cyprus DSO. Despite the primary level of the Cyprus regulatory framework, EAC(DSO) is after its 2050 vision through a well-structured strategy. Undoubtedly, GOFLEX has provided invaluable lessons for the era to come, rendering EAC(DSO) more knowledgeable to pursue its strategic targets. Following are the distinctive insights gained:

2.2.1 GOFLEX innovative approach gives substance to new DSO business models:

GOFLEX’s innovative extension of the European Harmonized Electricity Model to account also for the structuring of the monopolistic-grid part of the market. The principle of such an extension lies in the fact that problems are addressed easier at local (distribution) level as opposed to system level (transmission), introduces new business models and illustrates the new DSO role as a service procurer in addition to its service provision and neutral market facilitation. Such evolvements are also provisioned in the EU Clean Energy Package. GOFLEX demystifies the new DSO role depicting a new responsibility to locally balance the energy flows in the distribution grid and tackle grid congestion optimally, both technically and financially. The ultimate GOFLEX target is to provide an end-to-end platform and tools to enable a CBA to substantiate flexibility as cheaper alternative to conventional solutions to tackle increased distributed generation penetration. In particular, the Cyprus demo site has focused on the congestion avoidance use case through procurement of local flexibility as opposed to grid infrastructure reinforcement. The latter approach is inefficient as the new infrastructure is widely underutilized. A detailed techno-economic analysis is provided in §5.

2.2.2 GOFLEX positions DSO as an equal operator to TSO - Coordination is a must:

GOFLEX is a transparent holistic solution as it supports a diverse collection of use cases, covering all market players (system operators, aggregators, suppliers, BPRs) under various market environments. When it comes to DSO's GOFLEX use case, the congestion avoidance is the prominent but others also apply effectively. For Cyprus with a single DSO, the most important use case is that of a distribution BRP. This is a GOFLEX invention stemming from the further structuring of the grid. Similar to the TSO role, a new DSO role as system operator will be to delegate local balancing responsibility to one or more distribution BRPs (sub-BRPs), which in turn shall procure flexibility services from FSP (Flexibility Service Providers), e.g. aggregators or direct-trading flexible prosumers. The energy flow shall be between the DSO and FSP but contracts/financial flows between DSO⇔BRP(s) and BRP⇔FSPs. In general, a separate Local Flexibility Market Operator is required, especially in the case of more than one BRPs, not excluding the DSO or a subsidiary if procured services are limited to ancillary services. If only a single BRP exists, it is rational that DSO or an own entity will have this role. In addition, it is reasonable to merge the balancing responsibility of the DSO/BRP to the market operator role, especially if only ancillary services are concerned. This applies to Cyprus' case with a single DSO and a small grid.

In any model, this local balancing role of the DSO at the TSO-DSO boundaries is aiding the TSO at balancing the Market Balancing Area. The DSO shall resolve any imbalance by procuring balancing energy from FSPs at distribution level (but not the transmission level). The business case for DSO is from the split of network tariff with the TSO Vs Balancing Energy Costs + Operational Costs. The split of the network tariff with the TSO is based on avoided costs of balancing the local grid by local balancing as opposed to balancing regionally by TSO. There are two main contributors: reduction of energy transport costs (grid capacity and operation) and reduction of costs of balancing energy through intensive use of energy flexibilities (positive and negative). This means that the investments into dedicated peaker stations are avoided or largely reduced, as the energy flexibilities are supplied by prosumers with installed process equipment; the investment is reduced to control and management systems and adaptation of environment.

A fundamental principle is that TSO and DSO flexibility requirements may be conflicting, turning TSO-DSO cooperation a significant prerequisite that optimally dictates a joint design of flexibility market model, defining TSO and congestion and balancing platforms, their interaction, as well as trading model with Flexibility Service Providers.

2.2.3 Integrated/Unified GOFLEX approach towards solutions, but reserving modularity suiting proprietary needs:

GOFLEX has managed to deliver an end-to-end full-suite platform incorporating all relevant players: end-users (prosumer and producers of different flexibility capacity), including microgrids and energy communities, flexibility aggregators, BRPs, system operators, and potentially every entity that requires flexibility. GOFLEX has integrated all solutions to accommodate all players' requirements, providing a single, unified total solution for local flexibility. GOFLEX has provided knowledge and insights to the DSO, enabling him to pursue a regulatory framework on DSM, congestion and balancing management, together with the TSO and Regulator.

Despite GOFLEX being a full-blown solution, the platform reserves modularity as the building blocks can be applied individually or as an integrated system depending on the needs of the related market actors. What's more, the solution provides open interfaces to allow for the integration of legacy systems (e. g. existing SCADA), rendering it potentially interoperable and replicable to be integrated into the DSO's systems currently under development (e.g. distribution SCADA).

It's a distinctive add-on that the Cyprus DSO has the opportunity of further testing and upgrading the GOFLEX solutions through the "continued exploitation of GOFLEX". Continued exploitation is the opportunity to continue operation of the demonstrated solutions for two years after the end of the project. The experiences gained through extended observation, tracking and upgrading of the systems can be used on the one way to hone the technical and user-oriented features of the solutions and on the other, the demonstrated instances of GOFLEX solutions can be used by the DSO to pave way to the shaping of the markets.

2.2.4 Acquaintance with open protocols and technologies:

EAC(DSO) has gained much on the technology pylon, towards its roadmap implementation to grid transition. A prerequisite for the grid transition is the integration of ICT and control technologies (ICCT, Information, Communication, Control Technologies) into the distribution, aiming to transform it from its current ignorant state to probably the smartest part of the energy system This is only possible through convergence of ICCT within the power grid chain.

GOFLEX has exploited edge technologies and open protocols to achieve automated operation of a rather complicated end-to-end flexibility platform. GOFLEX solution providers have guided EAC(DSO) into integrating and operating these technologies and protocols. It's been a beneficial contact for EAC(DSO) as it provided a first class deep acquaintance with the prevailing smart grid enabling technologies and has verified the need for the DSO to shape its own ICCT core to support the energy transition.

GOFLEX technologies and solutions provide valuable tools enhancing real-time grid state observability and forecasting, DOMS being the heart of this. EAC(DSO) is much in need of this automated grid state knowledge in times where a usual DSO day will need to focus on solving issues, indeed in an automated way, let alone identifying them. DOMS has proved to unleash EAC(DSO)'s hands in this respect, as if it is served with required grid data, it predicts grid issues and in addition it takes suitable measures to mitigate them through targeted flexibility procurement. Such a tool as DOMS, could be potentially integrated into the distribution SCADA to account as a balancing / congestion management tool and maybe play a crucial role in TSO-DSO coordination if the model to be pursued is based on different balancing / congestion management platforms.

2.2.5 1st time of explicit tariff/dynamic pricing for EAC(DSO):

Even though EAC(DSO) has previous experience with implicit tariffs through a Time of Use (ToU) retail tariff for prosumers, it was the first time with GOFLEX that EAC applied and tested explicit tariffs through dynamic flexibility pricing. In terms of the congestion avoidance business case, this dynamic flexibility pricing provides a localized, targeted solution that changes the way DSOs will operate in the future, and a first class lesson to EAC(DSO) towards its transition to a diverse holistic system operator. What's more, it illustrates that the DSO business will shift gradually from CAPEX-intensive to OPEX-intensive, paving the way for pertinent discussions with the regulator in an effort to adapt the current regulated reimbursement provisions.

2.2.6 Additional stakeholder roles insights:

Due to the diverse solutions implemented with the GOFLEX platform and applied to the Cyprus demo site, it was necessary that some players are substantiated by EAC(DSO), such as the Marker Operator (FMAR), BRP, Aggregator of delegated prosumers (FMAN), and potentially Energy Services Company that will provide access to flexibility for the direct trading prosumers. EAC(DSO) has taken part in these roles and had the opportunity to see at first hand the total suite of solutions, including installation, setup, and operation of hardware, software and user interfaces.

It's been a sweet burden for EAC(DSO) as we have drawn great experience on the required competencies, resources of the future market players that will actually sell flexibility to the DSO. We have also gained valuable insight on the various technical problems for the integration of demand-response ready users, such as communications in the Home Area Network, installations restrictions due to existing home configuration and infrastructure, as well as restrictions of conventional (non-smart) home appliances.

3 Prosumer Experience

3.1 End-users

3.1.1 Lessons learnt

Recruitment

Initially, EAC contacted a list of prosumers that qualified by specific criteria, such as installed smart meters (grid and PV) and proposed them to participate in the GOFLEX project. The purpose of GOFLEX project had been clearly defined while the concept of flexibility had been explained to each user. It was not easy for prosumers to understand flexibility with explicit dynamic pricing, as there was not such previous experience. It is worth noting that prosumers main incentive was monetary. At that time, details of installation specifics and operation were not completely known; hence, we could not convey details requested from candidates. This resulted in some refusals to participate, already from recruitment stage.

Planning

Afterwards we visited all the houses of the prosumers that had agreed to participate, in order to develop an installation implementation plan. The aim was to identify some lighthouse prosumers that would be treated as representative cases. Once their plan was ready, that could serve as a guide for similar/follower prosumer cases with minimum effort. As described in detail in D7.3, the plan consisted of many sections, most significant being the premise blueprint, the identification of potential flexible devices and proposed interventions.

The premise blueprint revealed the position of critical equipment, such as meter cabinet, internet gateway, and potential devices. Based on the restrictions of each system (HEMS, non-HEMS), the premise restrictions, potential devices, and prosumer preferences, the prosumer was included in a specific category and his flexible appliances were selected provided the prosumer gave his consent. The flexible devices that have been selected were mainly washing machines, dishwashers, air conditioners, freezers and dryers. Finally, a complete installation implementation plan was conducted for each user, representing the installation location of each equipment.

It is worth noting that during planning we faced the most refusals. This is because both premises and systems restrictions dictated some interventions that were not easily accepted by prosumers, even at planning phase. For example, a HEMS panel was required to be installed next to the meter cabinet which is usually located in the premise perimeter, next to the main entrance for the prosumer of Figure 4.

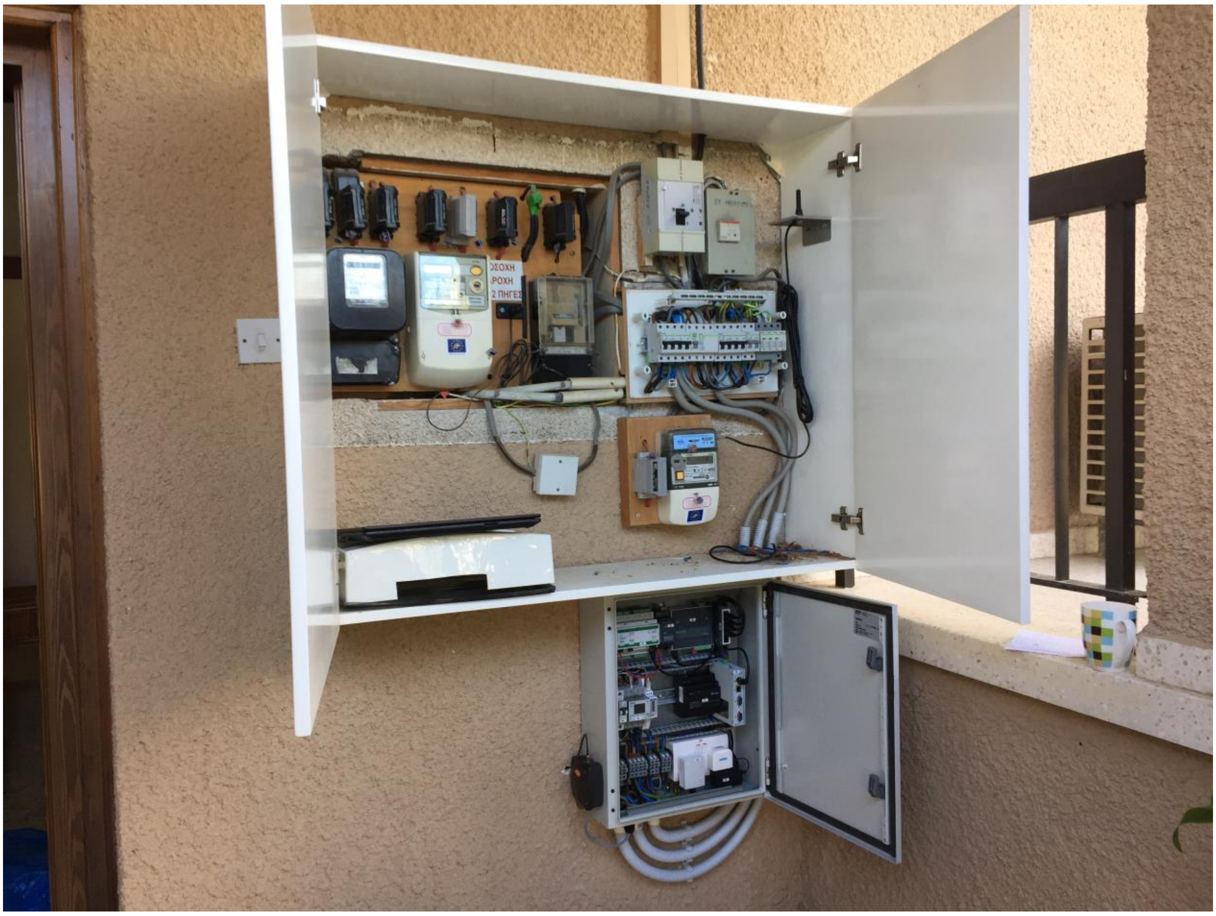


Figure 4: HEMS installed next to meter cabinet at a prosumer

Another issue was that the communication between HEMS and flexible appliances is with Zig-Bee, but many times the signal was not adequate and relocations of the Zig-Bee gateway were required. These relocations meant interventions in peoples' premises, that were not always welcome. An example of a Zig-Bee gateway relocation with an extension of around 10m is depicted in Figure 5.

Non-HEMS prosumers supported WiFi communication which turned to have higher range and even though some restrictions were faced, they were more straightforward.

Figure 5: Zig-Bee gateway relocation at a HEMS prosumer

As a result of the above peculiarities, the target number of users of not achieved, namely 18 instead of 20.

As for the CEMS use case, we faced unforeseen interoperability issues of the EAC Central Charging Management System with the charging stations. In fact, the system did not support the required OCPP1.6 for charging management, and in an effort to fulfill its obligations, EAC has acquired the OCEAN system. However, the existing EAC charging stations proved not to be fully compliant with OCPP1.6, even after an upgrade. Left with no other option, EAC and ETREL cooperated to implement the CEMS use case at two new charging stations that were OCPP compliant. Although the aimed target of four CEMS was not achieved, partners have successfully implemented and tested CEMS the use case. Lesson learnt is that planning phase should reach a mature level from proposal stage, in order to anticipate potential issues and take early action for mitigation. Such unforeseen technical bottlenecks are of course usual at such innovative projects with complex sets of technologies.

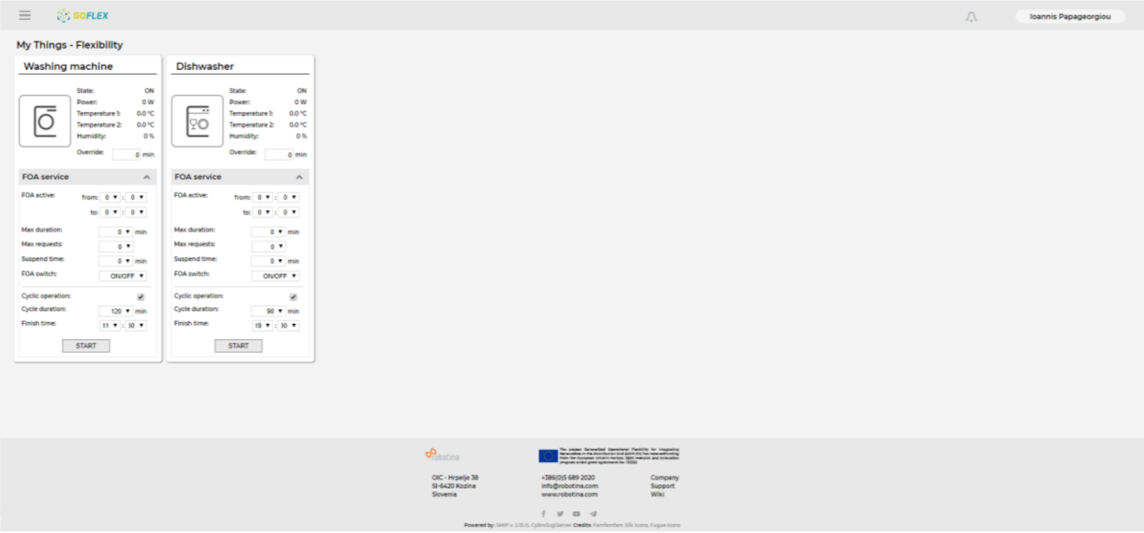
Installation/Initial Configuration

Installations were carried out by an experienced electrical contractor and all the required equipment has been installed in each prosumers house. Despite the contractor’s expertise, installations were not straightforward. EAC had obtained detailed guides for installation and initial configuration from the solution providers, but due to the complex technologies involved, the learning curve dictated the pace of installations. Local peculiarities also resulted in dealing with a different project at every premise, even though some of the prosumers were treated as representative. Hence, installation was most of the times not trouble-free. Of course, HEMS prosumers required extensive interventions, while non-HEMS required minimum.

Installation took place both outdoors and indoors, therefore prosumers needed to be available during installation, which posed some delays as installations followed the prosumers schedule.

Testing, setup and training

When GOFLEX platform was ready for operation end-to-end, we have visited each prosumer to test functionality. In close online cooperation with solution providers, functionality was tested and fine-tuned where required. The prosumers were in general present to this testing. Further, we have guided the prosumers to create accounts in the energy management systems and trained them how to use the systems for monitoring as well as to set their flexibility settings. It has been observed that delegated-trading prosumers (AAU) understood easily how to define their flexibility settings since they have to define their preferences only once. On the contrary, HEMS prosumers had a trickier task as cyclic "white" appliances need per use settings. In particular, each time they offer their flexible devices, "Finish Time" and "Cycle Duration" have to be set up, as seen in Figure 6. Based on the prosumers' feedback this was burdensome, however necessary from system design.



My Things - Flexibility

Washing machine
State: ON
Power: 0 W
Temperature 1: 0.0 °C
Temperature 2: 0.0 °C
Humidity: 0 %
Override: 0 min
FOA service
FOA active: from: 0 : 0 to: 0 : 0
Max duration: 0 min
Max requests: 0
Suspend time: 0 min
FOA switch: ON/OFF
Cyclic operation: ☑
Cycle duration: 120 min
Finish time: 11 : 30
START

Dishwasher
State: ON
Power: 0 W
Temperature 1: 0.0 °C
Temperature 2: 0.0 °C
Humidity: 0 %
Override: 0 min
FOA service
FOA active: from: 0 : 0 to: 0 : 0
Max duration: 0 min
Max requests: 0
Suspend time: 0 min
FOA switch: ON/OFF
Cyclic operation: ☑
Cycle duration: 90 min
Finish time: 19 : 30
START

Figure 6: Flexibility settings page at a HEMS prosumer

Also, it turned out that not all prosumers were ready to follow operation instructions, as this involved access from mobile devices or a PC, and a good acquaintance with graphical user interfaces. This is acceptable for middle-aged or older users, but reveals the gap between users awareness of edge technologies.

Trial operation period, SAT, regular operation

The platform was thoroughly tested for a trial period during which some issues were identified. More specifically, some prosumers' systems faced intermittent communications resulting in disruption of the controlled devices operation. The communications scheme that was eventually selected due to the abovementioned peculiarities is complex, featuring PLC in conjunction with DSL, and Zig-Bee. Also, some HEMS prosumers, did not always manage to set correctly their flexibility settings hence some of their available flexibility was not eventually provided to the platform.

During trial operation period two SATs were performed. At the first SAT all users were asked to activate their flexible devices at the same time in order to produce multiple flex-offers. The second SAT lasted a weeklong, and the consumers were asked to use their devices as much as possible in order to generate substantial flex-offers and test the platform at multiple circumstances and boundary conditions. All the issues identified during the SATs were solved in cooperation with solution providers.

Following the SATs, the regular operation period commenced, were all users were actively generating flexibility and the platform operated in a coordinated way trading it. During regular operation period, issues were frequently raised but solved through cooperation with either the prosumers or the solution providers. Such a complex platform cannot be left without monitoring for extended periods. Effective communication especially with users is necessary to attain smooth operation and user satisfaction.

As a concluding remark, the most important lesson learnt from user interaction is that the platform has to be user friendly, and as it is addressing users with diverse age and background. In addition, the user interaction with the software has to be limited as much as possible. Under any circumstances, the user must have the ability to easily control his devices. Also, our experience with the GOFLEX users proved that incentives are necessary in order to increase their active participation. It should be noted however, that the vast majority of users were extremely cooperative and carefully following our guidelines.

3.1.2 Users survey

User Survey Design

To get an overview of the prosumer experience with GOFLEX technology, we conducted a survey study at Cyprus demo site. This method was utilized as it is an appropriate research method for getting user experience responses from a large number of people within a well-established target group. A survey is an instrumental device that can capture how individuals interact with certain technology, what kind of problems they may be experiencing, and the kinds of actions they may be taking.

Survey Design

The user survey had four specific parts:

1) One part to report on the demographics of the respondents
2) One part to measure respondents' overall understanding and experience of GOFLEX technology (user experience, main purposes and benefits, and future concerns and motivation)
3) One part to measures respondents' experiences of GOFLEX technology related to the specific demo site use case (e.g. heating, washing)
4) One part to report on things respondents like or do not like and what their future needs may be.

We designed the survey with both closed- and open-ended questions. The open-ended questions are used to get a better understanding of participants' experiences and their needs. They can also provide more context behind participants' actions. The result from open-ended questions is typically a qualitative dataset. Closed-ended questions let respondents choose from a distinct set of pre-defined responses. The result from closed-ended questions is a quantitative dataset.

Most of the close-ended questions in the survey were designed to be measured on a 5-point Likert scale (from 1=strongly disagree to 5=strongly agree) with an additional “don't know” response option. We also included an “other (specify)” option for each of these. When participants respond to a Likert item, respondents specify their level of agreement or disagreement on a symmetric agree-disagree scale for a series of statements. Thus, the range captures the intensity of their feelings for a given question. We chose to measure based on the 5-point Likert scale as it is the most recognised approach to scaling responses in survey research.

Survey Participants and Data Collection

At the Cyprus demo site, all GOFLEX users were asked to participate in the survey. As they have different ways of interacting with GOFLEX components, we also took this into consideration in the logic and distribution of the survey.

The survey was sent out via mailing list compiled by EAC and distributed to users. The survey was hosted on SurveyMonkey, an online survey collection tool. The data collection period lasted 17 days, starting at the end of January 2020. The participating households had at this time experienced GOFLEX technology running for 5 to 6 months. All collected data were anonymised.

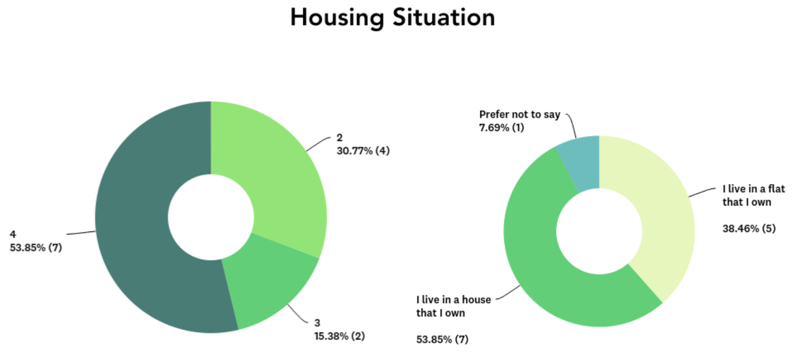
User Survey Results and Discussion

When we report responses measured on the 5-point Likert scale, we sort overall questions based on the weighted average. The weighted average (WA) represents the average of questionnaire responses over the set of individual item questions. Thus, a high weighted average (WA [<3-5]) means that on average respondents agreed to strongly agreed with the item question, while a low weighted average (WA [1->3]) means respondent disagreed to strongly disagreed with the item question. An average WA (WA ~3) means respondents neither agreed nor disagreed.

Characteristics of survey respondents

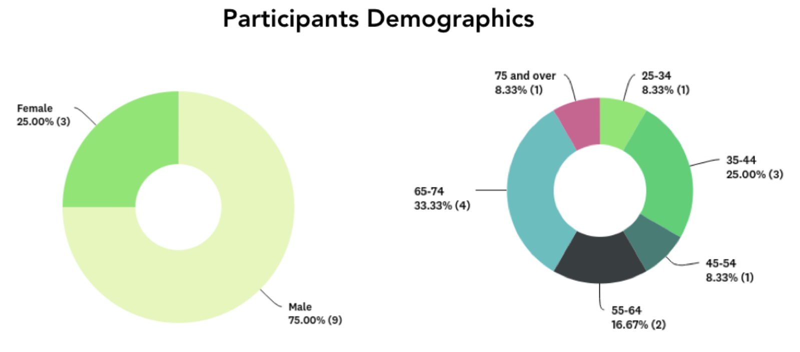
A total of 13 individual persons chose to participate in the Cyprus survey. This means that when reporting on the results of close-ended questions from the Cyprus survey, we are not able to generalise these results, but we can, however, observe some trends in the dataset.

From the collected data, we can see (Figure 7B) that most participants came from residential households owned by the participants either as houses (53.85%) or flats (38.46%). We can also observe that all respondents came from housing occupied with more than one person, indicating that the respondents came from multiple-family homes (Figure 7A). Mostly male respondents 75,00% participated from these households (Figure 7C), while 25,00% respondents were women. The ages of the respondents were spread out, stretching from the age of 25 to 75 and above (Figure 7D).



A: Numbers of household members

B: type of household



C: gender of participant

D: age of participant

Figure 7: Main characteristics of participants and their housing situation.

We asked the respondents who the main user of GOFLEX technology is in their household to determine the level of experience of interacting with GOFLEX technology (Figure 8). 75.00% reported that they are the main person responsible for controlling and interacting with GOFLEX in their households, while 25.00% reported that someone else in their household had that responsibility.

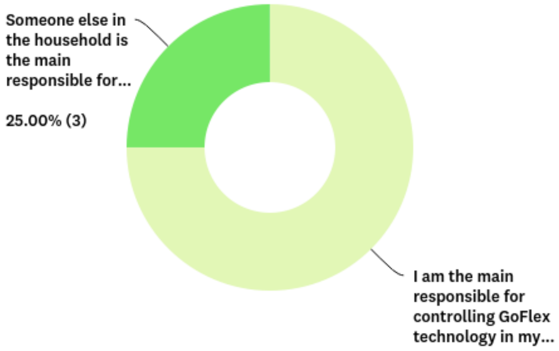


Figure 8: Experience of interacting with GOFLEX technology.

The respondents were also asked what motivated them to participate in the GOFLEX project (Figure 9). The respondents reported that the main motivational factor for participating in the GOFLEX project was wanting save money on energy usage (WA: 4.45). Wanting to try out new technology was the second-highest ranked motivational factor (WA: 4.20), closely followed by doing something good for the environment (WA: 4.18). Doing something good for the local community was the least ranked factor (WA: 3.66).

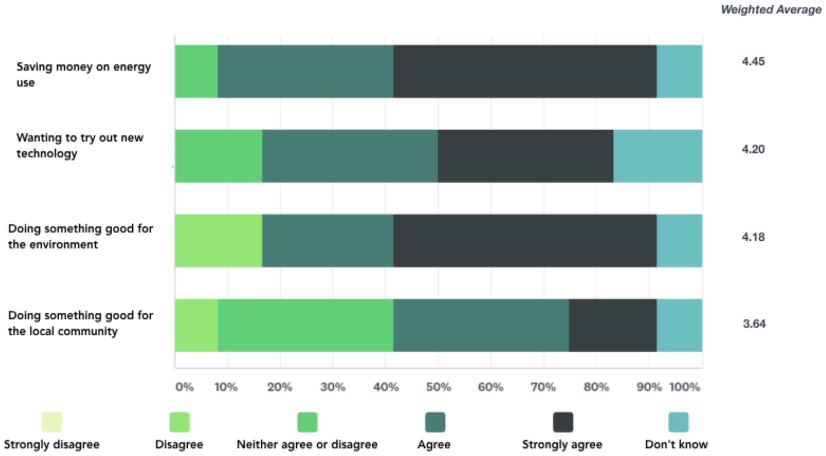


Figure 9: Motivational factors for participating in the GOFLEX project.

We also asked the respondents to describe GOFLEX technology with three words. The most common words were washing machine, flexibility, time shift and EAC (Figure 10). This indicates that the respondents had a fundamental understanding of both the technical aspects of the GOFLEX project (flexibility) and how it influences everyday life (washing machines).

Figure 10: Word cloud illustrating the words the respondents use to describe GOFLEX technology in Cyprus.

User experience of GOFLEX interactive components

To measure the user experience of the specific GOFLEX interactive component at the Cyprus demo-site, we asked questions about what GOFLEX technology controls in their home and how and why the participants interact with their GOFLEX interactive component.

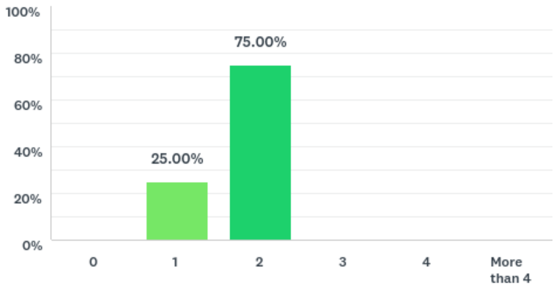


Figure 11: Number of electric devices controlled by GOFLEX technology

From the survey response, we can observe that in most households (75,00%) GOFLEX technology controls two electric devices (Figure 11), while GOFLEX technology controls one electric device in a quarter of the households. The most common device perceived to be controlled at the Cyprus demo-site is washing machines (66,67%), while freezers and A/C's are perceived to be controlled in a third of the households. In 16,67% of the households the dishwasher is perceived to be controlled, while a tumble dryer is controlled in a single household (Figure 12).

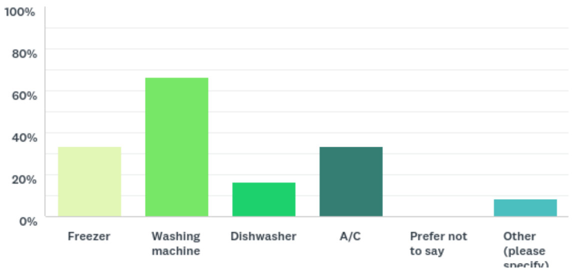


Figure 12: Respondents perception of what GOFLEX technology controls in their home.

From the survey response, we can also observe that a third of the respondents (33,33%) interact with the GOFLEX interactive app a couple of times a month (Figure 13), while a quarter interact with the site weekly or a couple of times every three months. When respondents use the GOFLEX interactive app (Figure 14), most respondents agrees or strongly agrees to seek information about how much energy their devices consumes, closely followed by the amount of energy the household produces of electricity. The rest of functionality e.g. changing settings of devices, seeking information about running times, KPI's, personal information or energy bill seem to be rarely used by the respondents at Cyprus demo-site.

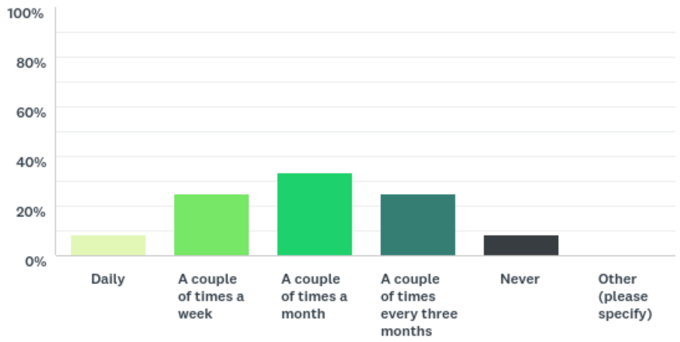


Figure 13: Number of times using the GOFLEX interactive app.

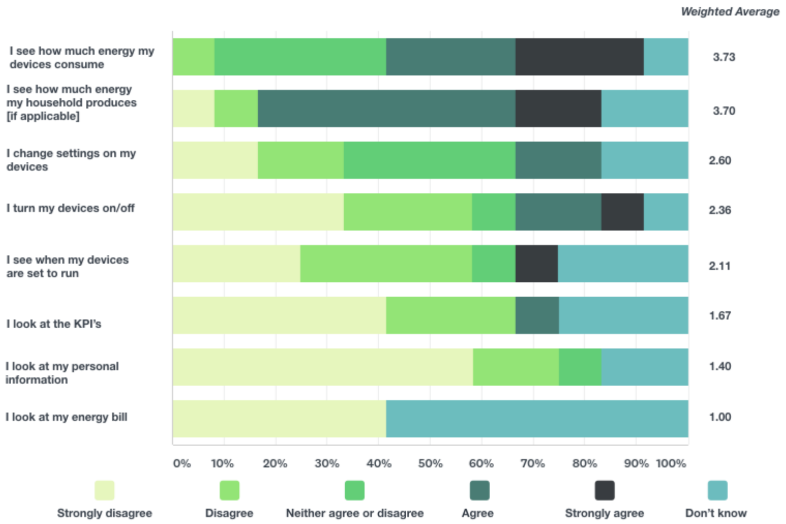


Figure 14: Use of the GOFLEX interactive app.

To get an indication of the overall user experience of interacting with GOFLEX technology, we asked questions measuring the usability (how much people believe the product makes their lives easier), and desirability (how much people believe it matches with them) of GOFLEX technology (Figure 15). All usability questions had a weighted average 4.46, while desirability questions had a weighted average 3.41. Together this indicates that the respondents perceived the overall user experience of GOFLEX technology to be rather good to great.

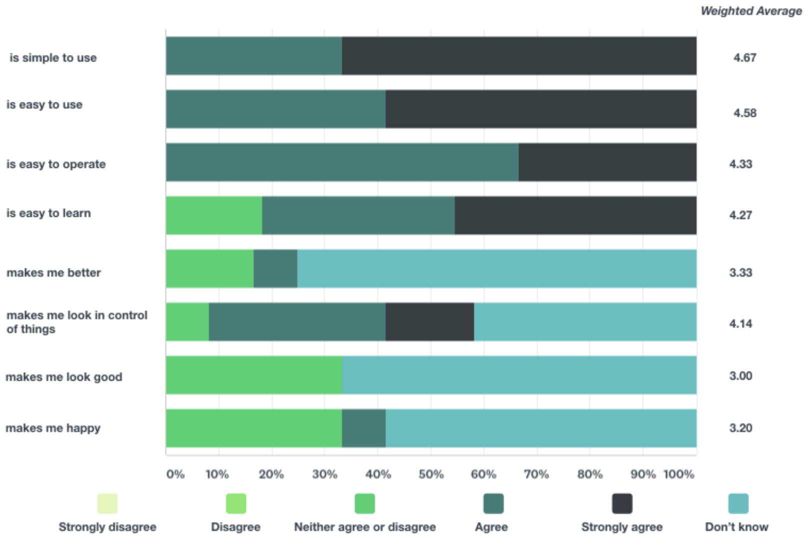


Figure 15: **Overall user experience of GOFLEX technology**

The participants were also asked if they had experienced any inconveniences related to household activities influenced by GOFLEX technology (Figure 16) 58.33% of the respondents agreed or strongly agreed that to wash dishes, and to heat or cool have remained the same after

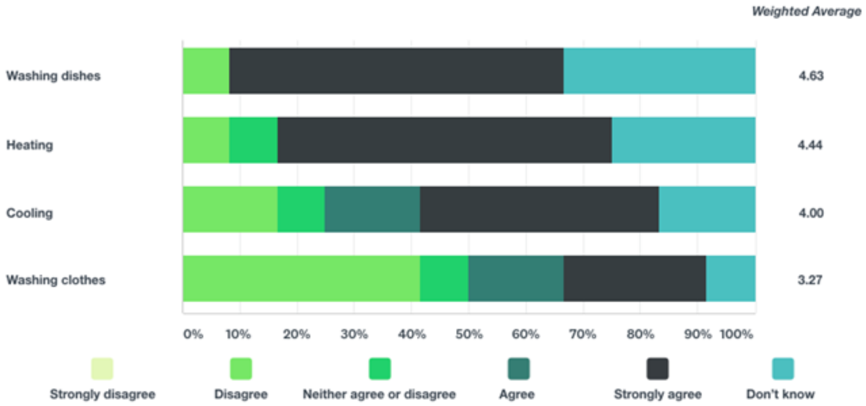


Figure 16: Through GOFLEX technology, the convenience to perform certain activities has remained unchanged.

GOFLEX technology has been installed in their home. The only activity in which a majority of respondents felt inconveniences was washing clothes with 41.67% of the respondents disagreeing that this activity had remained the same. When asked about how often respondents experienced inconvenience , (Figure 17) 50% responded a couple of times every three months, 33.33% experienced this a couple of times a month, while 8.33% experienced inconveniences weekly or never. None experienced inconveniences daily. These results indicate only few of respondents have experienced inconveniences after GOFLEX technology has been installed in their homes.

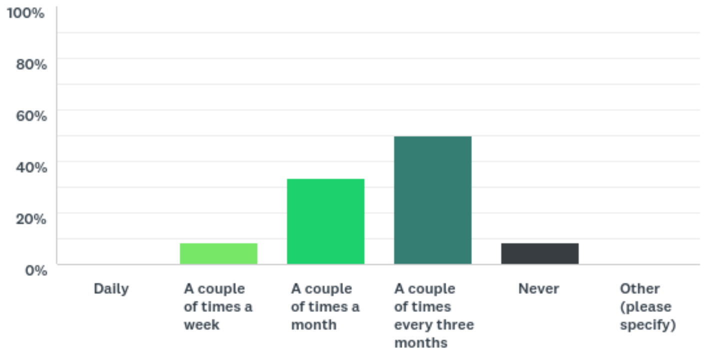


Figure 17: Number of times experiences of inconveniences due to GOFLEX technology.

User Expectations of GOFLEX Technology

We created different questions to measure respondents’ perception of the purpose and design attributes of GOFLEX technology. To measure the respondents’ perception of the overall purpose GOFLEX technology, we asked the specific questions related to the purpose of GOFLEX technology (see Figure 18). The respondents clearly perceived the main purpose of GOFLEX technology is to help them control energy-consuming appliances with 58.33% respondents strongly agreeing to this. At the same time 58.33% agreed that the purpose of GOFLEX technology is to provide information about their energy use. However, it is interesting to observe that 58.33% of respondents agreed the purpose of GOFLEX technology is to help them use less energy, while 33.33% agreed that the purpose of GOFLEX technology is help them use clean energy. Despite respondents using words like flexibility and time shift when describing GOFLEX technology, this result could be an indication that it is not clear for all participants what the overall purpose of GOFLEX technology is for them (as one vision of the project is the penetration of distributed renewable energies and not to facilitate less energy usage). This suggests that in future development the overall purpose could be better ascribed in the design of technology.

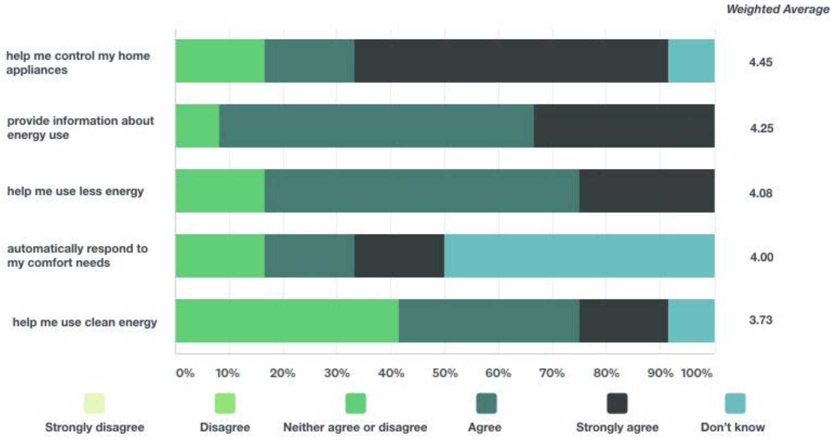


Figure 18: Perceived purpose of GOFLEX technology.

We also asked respondents what they perceived to be the main benefits of GOFLEX technology (Figure 19). The respondents clearly perceived the main benefit of GOFLEX technology is to save money with 100% of the respondents agreeing or strongly agreeing to this, while 83.33% of the respondents agreed or strongly agreed that the benefit of GOFLEX technology is to manage their energy use. 50% of the respondents agreed that the main benefit is an increased value of their property and to improve residents' lives, while most disagreed that main benefits of GOFLEX technology is make things effortless or provide comfort. Lastly, 66.67% of the respondents strongly disagreed that the main purpose of GOFLEX technology is save time.

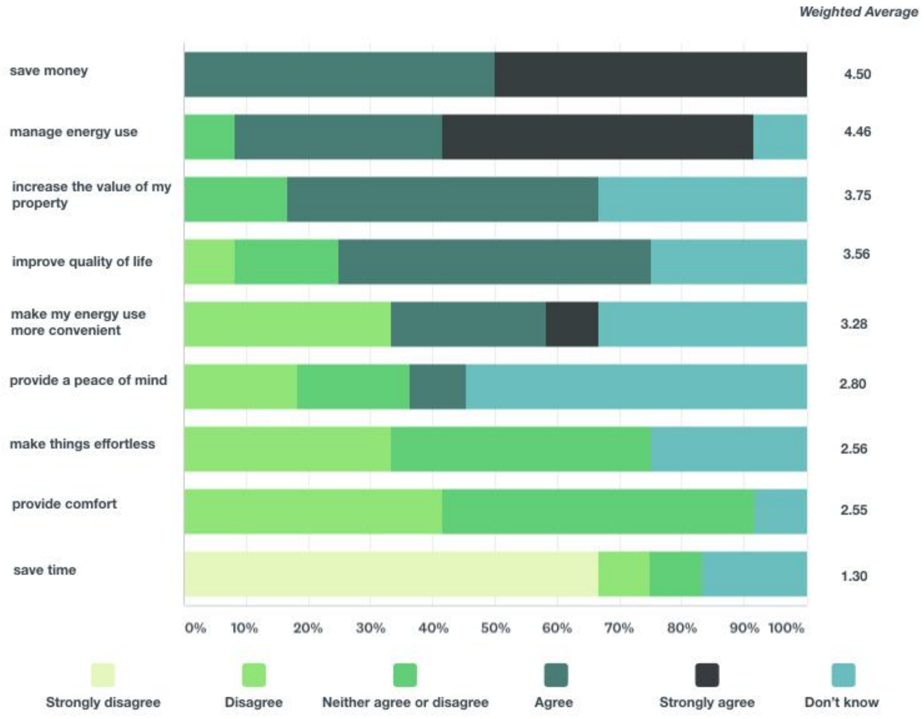


Figure 19: **Perceived benefits of GOFLEX technology.**

To measure the respondents' perception of what GOFLEX technology is designed to do, we asked the specific questions related to the design and control of GOFLEX technology (Figure 20). The respondents clearly perceived that GOFLEX technology is designed blend into the background of everyday life, closely followed to provide more information about what energy each individual household consumes. 75% agreed or strongly agreed with this, which could be related to that they also weighted this to be one of the main purposes of GOFLEX technology (Figure 18). As the users, at the Cyprus demo-site do have options to influence how GOFLEX technology is operating, it is interesting to observe that most of respondents agreed or strongly agreed the GOFLEX technology is designed to provide them with greater control over household activities rather than to help them manage their energy use, or designed to manage this for them. At the same time 83,33% of respondents agreed or strongly agreed that GOFLEX technology is designed to always be on and active, with the same amount of the respondents agreeing or strongly agreeing that GOFLEX technology is designed operate only when activated. This indicates that respondents are not able to distinguish between GOFLEX technology controlling their energy use on their behalf or if GOFLEX technology supports them to control their energy usage. These results imply that it is unclear for users what the balance is between system automation and user control in the design of GOFLEX technology. It suggests that designers and developers of future technology need to better convey to users where this balance lays and who is responsible for what.

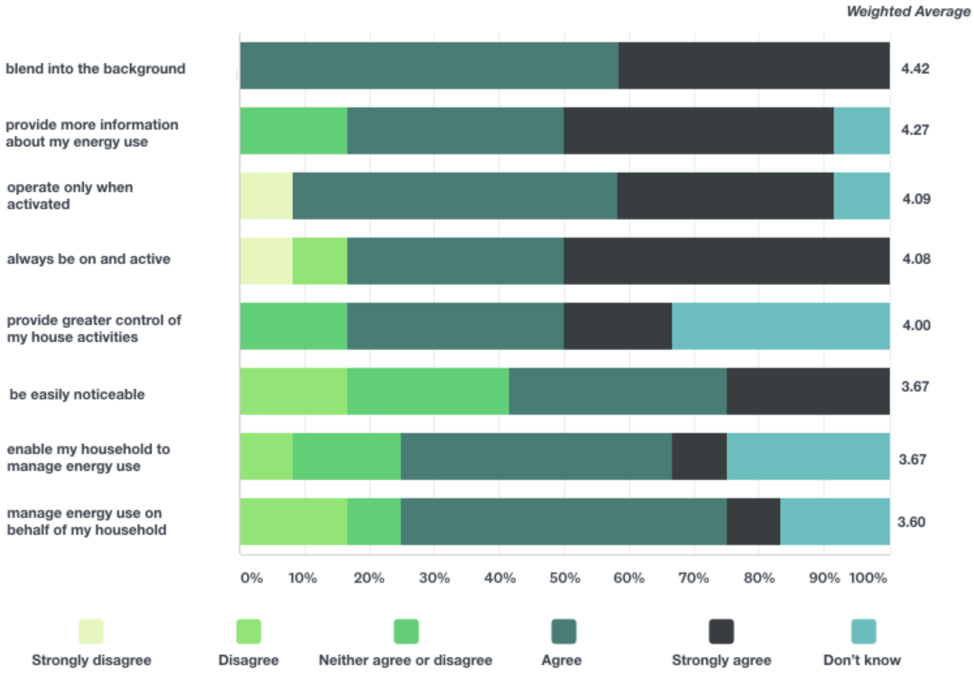


Figure 20: **Perception of the design and control of GOFLEX technology.**

Future Use, Risks and Improvements of GOFLEX Technology

We created different questions to measure respondents' perception what GOFLEX technology must do for them to continue to use GOFLEX technology and as well as general future risks and information improvements of GOFLEX technology.

To measure the respondents' perception what GOFLEX technology must do, for them to continue to use GOFLEX technology, we asked specific questions related to the use and features of GOFLEX technology (Figure 21). Survey respondents clearly thought that GOFLEX technology must securely hold all collected data. A total of 91,67% of the respondents agreed or strongly agreed with this. A further 100% thought that GOFLEX technology must be controlled and over-ridden by them. This indicates security and control are features respondents at the Cyprus demo site found to be of high importance when it comes to living along with GOFLEX technology in their everyday life. The least weighted averages of the features were managing energy use effortless and convenient and automating energy usage. This is rather interesting as these are some of the key design features of GOFLEX technology.

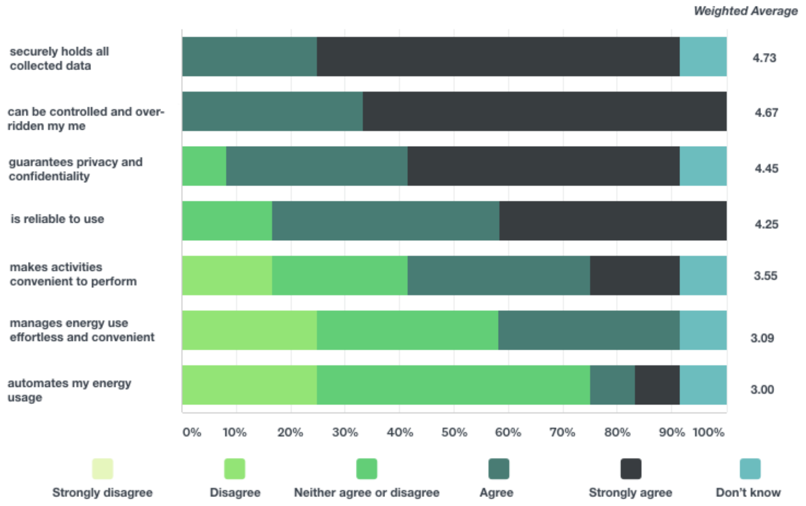


Figure 21: **Perception of the importance of GOFLEX technology features for future use.**

To measure the respondents' perception of the kinds of risks they associate with continued use of GOFLEX technology, we asked them seven specific questions related to this (Figure 22). With this, there is an indication that respondents associate use of GOFLEX technology with an increased risk of dependency of technology and outside experts. This suggests that these risk factors should be considered in future development as most of respondents (91.67%, and 83.33%) agreed or strongly agreed on these factors being a risk in the future. Interestingly, only 16.67% of respondents agreed that there was a risk of decrease of their comfort. The rest of the response options means were scored close to the midpoint of the response scale. This might be an indication of that respondents already associate GOFLEX technology as being rather trustworthy after already having experienced living with GOFLEX technology in everyday life.

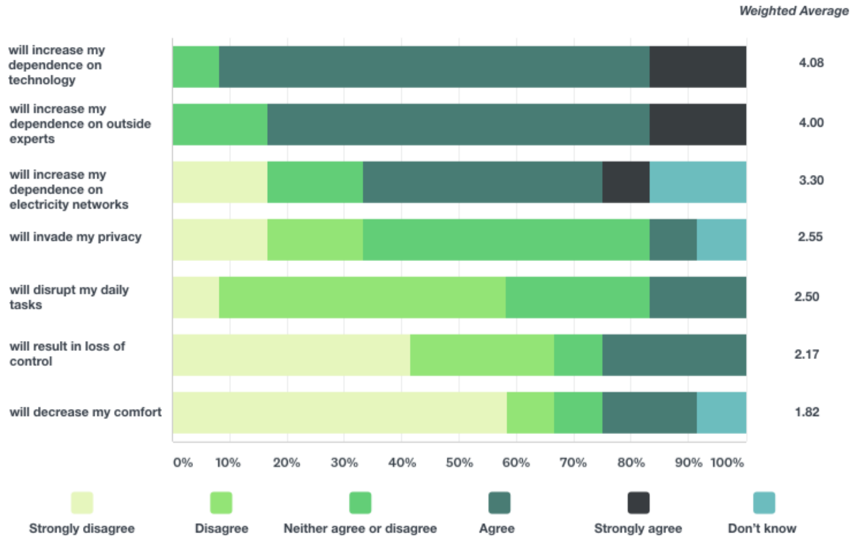


Figure 22: **Perception of risks associated with continued use of GOFLEX technology.**

To measure what information respondents perceived to be of importance for the continued use of GOFLEX technology, we asked them 10 specific questions of this (Figure 23). The respondents clearly agreed and strongly agreed that they need more financial information about what kind of money saving GOFLEX technology can facilitate. This specific need could be indication of why these respondents were motivated to participate in project in the first place, as wanting to save money on energy usage was ranked the highest motivational factor for participating in the GOFLEX project. Being able seek information about both general energy use and renewable energy usage (green energy usage and CO2 footprint) were generally ranked high by the respondents. For instance, being able to compare household energy usage over time had the second highest weighted average of importance of the information features with 90.91% of the respondents agreeing and strongly agreeing with this. This highlights a need to properly inform users about the benefits of GOFLEX technology controlling energy consuming devices in their homes in future development. Interestingly, information about the influence of GOFLEX control were ranked lower than the mid-point means on the response scale. This could be an indication that this kind of information is already accessible to these users in the applications they have access to. Being able to compare energy usage in the neighbourhood and getting information about the neighbourhood's renewable energy consumption had the lowest weighted average, with most respondents disagreeing or strongly disagreeing with these two information items being of importance.

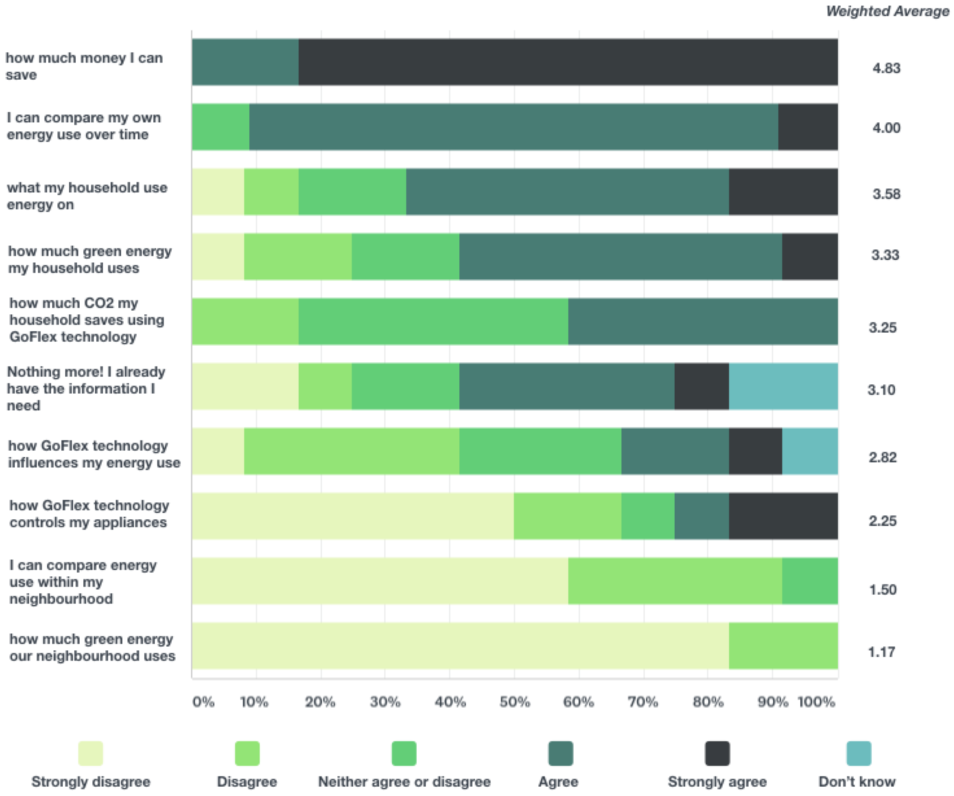


Figure 23: **Perception of important information for continued use of GOFLEX technology.**

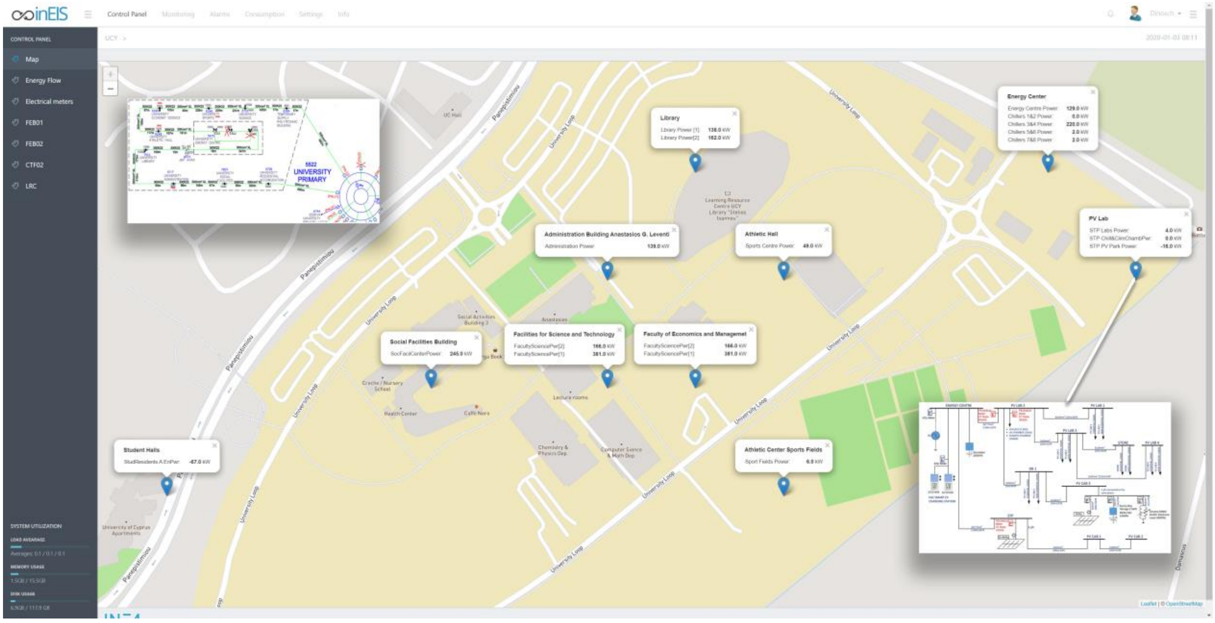
3.2 Energy Community/Microgrid

In the case of the University microgrid there are PV installations of more than 400 KWp, which are installed on both rooftops and in the terrain of the university. Furthermore, many buildings of the university campus have Building Energy Management Systems (BEMS) for mainly controlling the heating/cooling needs. A large PV park (10 MWp generation) and a battery storage bank (more than 7.5 MWh capacity) is planned to be installed within the university campus within the coming years. Moreover, new buildings (school of engineering, biology and school of medicine) are also under construction and will be gradually completed until 2021. Therefore, new BEMSs are going to be installed to control the new buildings. In order to increase the efficient operation of the whole microgrid, a monitoring system of the microgrid has been installed, integrating initially four BEMSs and eventually all of the rest, the respective sensors and new smart metering that have been installed, in a single point of control.

In order to assist the GOFLEX project objectives, the inEIS centralized energy management system has been commissioned in August 2019. To enable this, 18 smart meters have been installed in order to track the energy consumption of all the university buildings, related loads and PV generation. In addition to energy measurements, by interacting with BEMSs and exchanging information with other GOFLEX applications, predicts the amount of available energy flexibility by considering weather data and PV generation forecasts. By operating in such a way, the university aim is to maximise its self-consumption / minimize energy cost and dynamically match its energy demand against the grid’s available capacity. Furthermore, FOSS acting as the local BRP of the microgrid uses the data to trade flexibility according to the needs of the DSO (EAC in Cyprus case).

Furthermore, the case of including in the flexibility offers the EV charging/discharging station is also included. The EV station has been installed within the university campus (close to FOSS lab facilities) and together with the charging / discharging energy management system (CDEMS) provided by Robotina that is used to charge / discharge a 3kWh battery together with three electric motorcycles also facilitates trading of flexibility.

In this domain, the objective of Demonstration Case 1A was to emulate all market activities at a smaller and more controllable scale within the microgrid through simulations and actual measurements.



Library
Library Power [1]: 138.0 kW
Library Power[2]: 162.0 kW

Energy Center
Energy Centre Power: 129.0 kW
Chillers 1&2 Power: 0.0 kW
Chillers 3&4 Power: 220.0 kW
Chillers 5&6 Power: 2.0 kW
Chillers 7&8 Power: 2.0 kW

Administration Building Anastasios G. Leventi
Administration Power: 139.0 kW

Athletic Hall
Sports Centre Power: 49.0 kW

PV Lab
STP Labs Power: 4.0 kW
STP Chill&ClimChambPwr: 0.0 kW
STP PV Park Power: -16.0 kW

Social Facilities Building
SocFacilCenterPower: 245.0 kW

Facilities for Science and Technology
FacultyScienceFwr[2]: 166.0 kW
FacultyScienceFwr[1]: 381.0 kW

Faculty of Economics and Managemet
FacultyScienceFwr[2]: 166.0 kW
FacultyScienceFwr[1]: 381.0 kW

Student Halls
StudResidents A EnPwr: -67.0 kW

Athletic Center Sports Fields
Sport Fields Power: 6.0 kW

Figure 24: Central Management System inEIS showing the position of Smart Meters

During the course of the GOFLEX project it was anticipated that a 10 MWp PV system together with a 7.5 MWh of battery storage would have been available which would improve self-consumption and minimise energy costs through DSM (balancing captive supply and demand). This however has yet to be materialised due to various internal reasons something that limited the amount of flexibility of the microgrid.

The main electrical load of the university is the cooling system which is placed centrally at the Energy Centre (ENC). Boilers for central heating and Chillers for cooling are using pipes to transfer the hot or cold water to each building. Each building is controlled by the BEMSs. Ten BEMSs with different specifications, covering 10 university buildings, would have been integrated and operated through the central energy management system. However, due to the fact that some of them using proprietary interfaces required high costs to be integrated, it has been decided to initially integrate only four of them that required less expenses and based on the experiences gained by the operation of them proceed to the rest of the BEMSs in the near future. Exhaustive tests have been carried out to correlate changes of building room temperatures with power changes at the ENC. No significant energy changes were noted which can be attributed to the fact due to the system design, being a central system operating on peripheral buildings, it is a very slow system to react to changes in room temperatures. The fact that only 4 out of ten buildings were implemented made the situation even worse. Concerning, PV generation, the systems employed by the University until now are from Solaredge. The Solaredge API server is used for collecting the measurements from the inverters of PV system, the integration of which to the energy management system has not been straight forward and created some delays. Finally, the difficult task to persuade people for even small changes must be noted.

4 Technical Performance

4.1 Scale of Installation

Table 1: presents the scale of installation achieved at the Cyprus demo site.

Table 1 Scale of installation

Quantity	Related LCE-02 objective (labelled as per DoA)	Target Value	Achieved Value
Number of [Central] Energy Management Systems (FMAR)	O1	2	1
Number of aggregated Energy Management Systems (FMAN)	O1	3	2
Number of xEMS	O3	20	18
Number of direct-trading prosumers	O3		14
Number of delegated-trading prosumers	O3		4
Number of BEMS	O3	6	4
Number of Charging Energy Management Systems	O4	4	2
Number of Charging-Discharging Energy Management Systems	O4	1	1
Number of buses/branches covered by distribution grid observability (microgrid/distribution)	O5	20+/50+	83/83
Number of time series captured in cloud service platform (SCADA/AMI)	O6	10-50/20	1872/476
Number of forecasting models deployed in cloud service platform	O6	50+	212
Number of weather points		10	15

The table shows that most targets have been achieved. The gap at FMAN and FMAR instances is owned to the microgrid use case where technical limitations have not rendered possible the internal optimization of flexible sources, however the microgrid use case offering flexibility to the market has been fully implemented and tested. Also the number of CEMS has remained below target due to technical incompatibility of a number of EAC's charging station; however this use case has been adequately tested.

In terms of scalability and replicability, the Cyprus demo site has provided input to the SRA of the GOFLEX platform with a draft methodology developed by the Task Force Replicability & Scalability Analysis of the BRIDGE initiative [5], yielding significant outcomes.

4.2 Detailed Performance Evaluation

4.2.1 Performance metric

The performance of the GOFLEX platform is evaluated by Key Performance Indicators (KPIs), both trackable by the platform systems and non-trackable that are derived analytically offline. GOFLEX KPIs have been presented in a previous deliverable, but for sake of completeness are hereby further referenced. Table 2 presents all KPIs, discriminating between trackable and non-trackable, and further denoting whether they are related with some business KPI, as these were declared in D7.2., §6. Business KPIs linked with specific services are shown in Table 3.

Table 2: List of Key Performance Indicators (Trackable and Non-Trackable)

Project Performance Indicator (order of appearance in DoA)	Explanation	Tracked at	Targets	Trackable KPIs	Related to Business KPIs
Electricity load adaptability level	The maximum energy variation of loads over the maximum energy consumption, in an hour. The degree that loads can vary their consumption.	FOA, FMAN, FMAR	>15%	4.1.1 Electricity load adaptability level	-
DR generated by virtual energy storage in demonstrated use cases	Energy demand variation with respect to peak demand. The real flexibility offered by controllable loads.	FEMS, HEMS, CEMS, CDEMS	>15%	4.1.2 Demand response generated by virtual energy storage in demonstrated use cases in the project (during 3 months' testing & evaluation period)	-
Benefit for aggregator	Profit for Aggregator per MW scheduled, over a year	FMAN	>€35,000/MW/year + €200/MWh	4.1.3 Benefit for aggregator	-
Lessen the burden of power grids through self-consumption	Level of delivered flexibility over overall consumption / peak consumption (HEMS / grid level)	HEMS , FMAR/DOMS,	>10%	4.1.4 Lessen the burden of power grids through self-consumption	-
Increase of prosumer involvement (Augmented DR)	Percentage of activated flexibility over all offered flexibility	HEMS, CEMS	>15%	4.1.5 Increase of prosumer involvement	-
Flexibility range at average occupancy of charging spots	Energy demand variation with respect to peak demand for the average occupancy. The real flexibility offered by controllable loads.	CEMS	10 / -30 %	4.1.6 Flexibility range at average occupancy of charging spots	-
Flexibility range for varying parking time	Energy demand variation with respect to peak demand for 2hrs and 8hrs occupancies. The real flexibility offered by controllable loads.	CDEMS	2 hours: +/- 10%	4.1.7 Flexibility range for varying parking time	-
			8 hours: +/- 25%		
Distribution grid stability through responsiveness of flexibility services	Delivered flexibility over requested flexibility in different time frames	DOMS	30 min (25% of DR)	4.1.8 Distribution grid stability through responsiveness of flexibility services	-
Grid state observability	# of observed state variables over all state variables.	DOMS	>80%	4.1.9 Grid state observability: near-real time (5min) and forecast (forecast 30min up to 24-48 hrs)	-
Likelihood of prediction of congestion	Frequency of correct prediction of occurrence of congestion	DOMS	>90%	4.1.10 Likelihood of Prediction of congestion (voltage/power-flow limit violation)	-
Accuracy of forecasts at prosumer, T/R, S/S level	MAPE of forecasts at prosumer and S/S level	SP	<10%	4.1.11 Accuracy of forecasts at prosumer, MV/LV transformer or substation level (energy demand, generation, flexibility)	-
Accuracy of forecasts at MG, BRP level	MAPE of forecasts at microgrid and BRP level	SP	<5%	4.1.12 Accuracy of forecasts at microgrid, BRP level (energy demand, generation, flexibility)	-
Latency/efficiency of data querying	SP responsiveness to data querying	SP	< 1 minute	4.1.13 Latency / efficiency of data querying	-
Latency/efficiency of data querying			< 5 minutes		
Latency/efficiency of data querying			< 30 minutes		
Capable of integrating large share of RES	The % increase in RES penetration owed to flexibility procurement. Computed for UCY campus	-	>15 %	-	-
Benefit for DSO	The monetary benefit from DSO derived from flexibility procurement in the grid congestion scenario.	-	€1M / MW	-	-
Avoid congestions: reduction of peak demand	The difference between Peak demand expected - Peak demand realized	-	>15%	-	√

Table 3: List of Business KPIs

Business KPIs	SERVICE
1.1: Number of flexibility offers traded with the DSO: 10 flexibility offers/day	**Microgrid offering flexibility to the DSO**
1.2: Activation of demand response strategies through the BEMS: 10/day	
1.3: Reduction of the total cost of electricity: 20% reduction compared with the current situation	
2.1: Number of flexibility offers traded with the DSO: 10 flexibility offers/day	**Prosumers offering flexibility to the DSO**
2.2: Activation of demand response strategies through the HEMS/Controllable load: 10/day	
2.3: Reduction of the total cost of electricity: 10% reduction compared with the current situation	
3.1: Increase the accuracy of the forecast: 20% reduction in the imbalance between the forecasted and actual dispatch.	**Provision of forecasted data to the DSO**
4.1: Number of activated flexibility offers for grid congestion relief: 5 offers /day	**Grid congestion relief**
4.2: Reduction in the total cost of new grid infrastructure: 20% reduction	

4.2.2 Detailed Method

Metric 4.1.1: **Electricity load adaptability level**	
Explanation:	The maximum energy variation of loads over the maximum energy consumption, in an hour. The degree that loads can vary their consumption.
Applies to:	FOA, FMAN, FMAR
Calculation method:	FMAR: $Energy\ Demand\ Variation = \frac{e_h^{max} - e_h^{min}}{e_h^{avg}}$ *Where:*

	e_h^{max} *is the maximum amount of energy offered to be consumed (or produced) during the period of the hour h,* e_h^{min} *is the minimum amount of energy offered to be consumed (or produced) during the period of the hour h,* e_h^{avg} *is the average (historical) amount of energy consumed (or produced) during the period of the hour h.* *The parameters are retrieved from FOs. Energy Demand Variation applies to the selected user in active group of FMAR (HEMS, CEMS, CDEMS, aggregated portfolio of microgrid and dispersed prosumers).* FMAN: $Consumption\ Adaptability\ Level = \frac{Consumption\ Avg.Variability}{Average\ Baseline\ Energy} *$ Consumption Flexibility Level (% of time periods with flexible consumption) *The parameters are retrieved from FOs. Consumption Adaptability Level applies to the selected delegated-trading user or aggregated portfolio.*

Metric 4.1.2: **Demand response generated by virtual energy storage in demonstrated use cases in the project**	
Explanation:	Energy demand variation with respect to peak demand. The real flexibility offered by controllable loads.
Applies to:	HEMS, CEMS, CDEMS
Calculation method:	HEMS: $\sum_{\substack{End-user\\ controllable\ loads}}^{Averaged\ over\ time} \frac{Offered\ flexibility}{Realized\ avg.\ consumption}$ Where Offered Flexibility is retrieved from FOs and Realized avg. consumption is measured in situ. KPI can be provided at user-level and total xEMS level, for a selected period.

Metric 4.1.3: **Benefit for aggregator**	
Explanation:	Profit for Aggregator per MW scheduled, over a year.
Applies to:	FMAN

Calculation method:	$Aggregator\ Profit = \sum G_{market} - \sum C_{market} - \sum C_{FOS} - \sum C_{fixed}$ Where G_{market} is the sum of market order gains, C_{market} the market order imbalances, C_{FOS} the prosumers rewards and C_{fixed} are fixed costs. KPI can be provided at FMAN level for a selected period.

Metric 4.1.4: **Lessen the burden of power grids through self-consumption**	
Explanation:	Level of applied flexibility over overall consumption (HEMS and grid level)
Applies to:	FMAR, HEMS, DOMS
Calculation method:	HEMS: It's calculated as realized consumption adaptability level: $Real\ Consumption\ Adaptability\ Level = \frac{Realized\ flexibility}{Total\ realized\ user\ consumption}$ Where Realized Flexibility is the actual flexible energy provided and Total realized user consumption is the actual total user energy. KPI can be provided for individual and total HEMSes as well for a selected period.

	FMAR/DOMS: $Real\ Consumption\ Adaptability\ Level = \frac{Realized\ flexibility}{Peak\ grid\ demand}$ KPI can be calculated at grid S/S level.

Metric 4.1.5: **Increase of prosumer involvement**	
Explanation:	Percentage of activated flexibility over all offered flexibility
Applies to:	HEMS, CEMS
Calculation method:	$Increase\ of\ prosumer\ involvement = \frac{Realized\ flexibility}{Total\ offered\ flexibility}$ KPI can be calculated for individual and total xHEMSes, at a specified period.

Metric 4.1.6: **Flexibility range at average occupancy of charging spots**	
Explanation:	Energy demand variation with respect to peak demand for the average occupancy. The real flexibility offered by controllable loads.
Applies to:	CEMS

Calculation method:	CEMS: $\sum_{\substack{CEMS\ user\\ load}}^{Average\ occupancy} \frac{Possible\ Energy\ Variation\ (UP; DOWN)}{Internal\ Schedule}$ Where Possible Energy Variation is retrieved from FOs and Internal Schedule represents the initially planned charging load (precisely, the planned energy to be delivered to EV batteries). KPI can be provided at user-level and total CEMS level, for a selected period.

Metric 4.1.7: **Flexibility range for varying parking time**	
Explanation:	Same as 4.1.6 (Energy demand variation with respect to peak demand) but for 2hrs and 8hrs occupancies. The real flexibility offered by controllable loads at specified occupancies.
Applies to:	CDEMS
Calculation method:	CDEMS: $\sum_{\substack{CEMS\ user\\ load}}^{2hrs/8hrs\ occupancy} \frac{Offered\ flexibility}{Realized\ avg.\ consumption}$ Where Offered Flexibility is retrieved from FOs and Realized avg. consumption is measured in situ. KPI can be provided at user-level and total CEMS level, for a selected period.

Metric 4.1.8: **Distribution grid stability through responsiveness of flexibility services**	
Explanation:	Delivered flexibility over requested flexibility in different time frames (30 min)
Applies to:	DOMS
Calculation method:	DOMS: $\sum_{Grid\ S/S} \frac{Delivered\ Flexibility}{Scheduled\ Flexibility}$ Where Delivered Flexibility is retrieved from measurements and Scheduled Flexibility is received from demand schedules. KPI can be provided at grid S/S level and total grid level, for a selected period (30 min here).

Metric 4.1.9: **Grid state observability: near-real time (5min) and forecast (forecast 30min up to 24-48 hrs)**	
Explanation:	# of observed state variables over all state variables.
Applies to:	DOMS
Calculation method:	Two different metrics were proposed to evaluate the Grid state observability capabilities provided by DOMS:

	$OBSERVABILITY.1 = \frac{Number\ of\ \text{observed}\ state\ variables}{Number\ of\ state\ variables}$ $OBSERVABILITY.2 = 1 - \frac{Number\ of\ \text{"metered"}\ variables}{no.\ of\ all\ available\ variables}$ The KPI “Observability.1” captures the number of observed grid state variables with respect to all possible states of interest (full observability). An alternative KPI “Observability.2” was introduced to capture the improvement in observability provided by DOMS with respect to raw observations available purely from current system telemetry (e.g. SCADA, metering infrastructure).

Metric 4.1.10: **Likelihood of Prediction of congestion (voltage/power-flow limit violation)**	
Explanation:	Frequency of correct prediction of occurrence of congestion
Applies to:	DOMS
Calculation method:	The performance of DOMS congestion predictions is evaluated using typical classification metrics of Precision, Accuracy and Recall: $ACCURACY = TP + TN$ $PRECISION = \frac{TP}{TP + FP}$ $RECALL = \frac{TP}{TP + FN}$

	based on true-positive (TP), true-negative (TN), false-positive (FP) and false-negative (FN) rates of the predictions of undesired state variable operational ranges.

Metric 4.1.11: **Accuracy of forecasts at prosumer, MV/LV transformer or substation level (energy demand, generation, flexibility)**	
Explanation:	MAPE of forecasts at prosumer and S/S level
Applies to:	SP, HEMS
Calculation method:	HEMS: $\text{Forecasting error} = \frac{\text{forecasted power}}{\text{realized power}}$ SP: MAPE calculation

Metric 4.1.12: **Accuracy of forecasts at microgrid, BRP level (energy demand, generation, flexibility)**	
Explanation:	MAPE of forecasts at microgrid and BRP level
Applies to:	SP but it’s not applicable at Cyprus demo site

Calculation method:	-

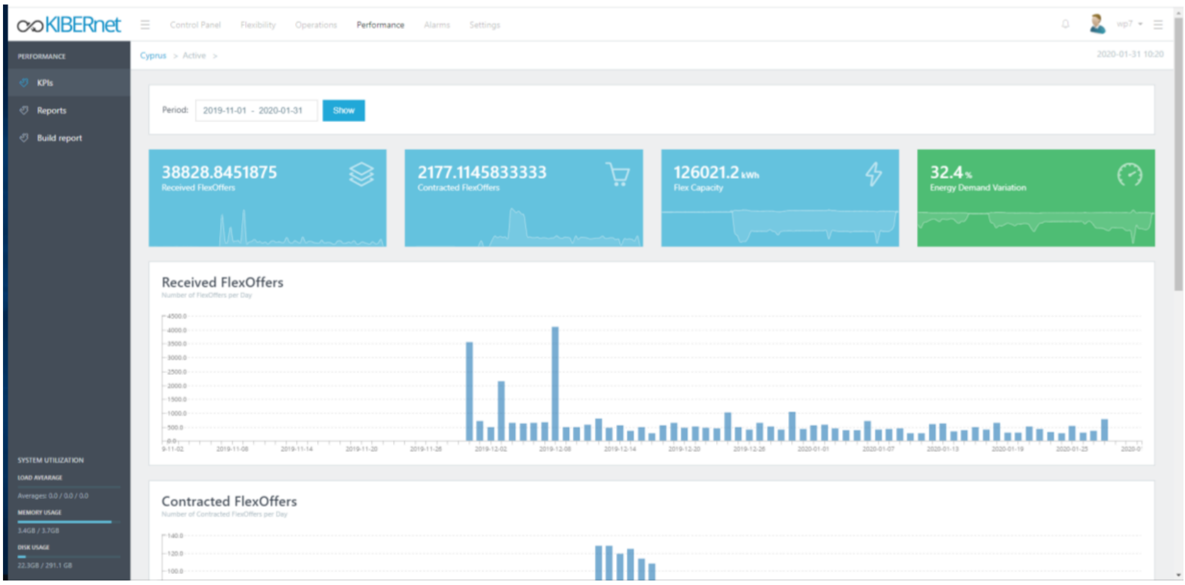
Metric 4.1.13: **Latency / efficiency of data querying**	
Explanation:	SP responsiveness to data querying
Applies to:	SP
Calculation method:	Extracted from the SP

4.2.2.1 Detailed Results

Metric 4.1.1:
Electricity load adaptability level

This metric is calculated at both FMAN and FMAR levels.

FMAR's parameter is "Energy Demand Variation" as shown in Figure 25.



Period: 2019-11-01 - 2020-01-31

38828.8451875 Received FlexOffers

2177.1145833333 Contracted FlexOffers

126021.2 kWh Flex Capacity

32.4 % Energy Demand Variation

Averages: 0.0 / 0.0 / 0.0

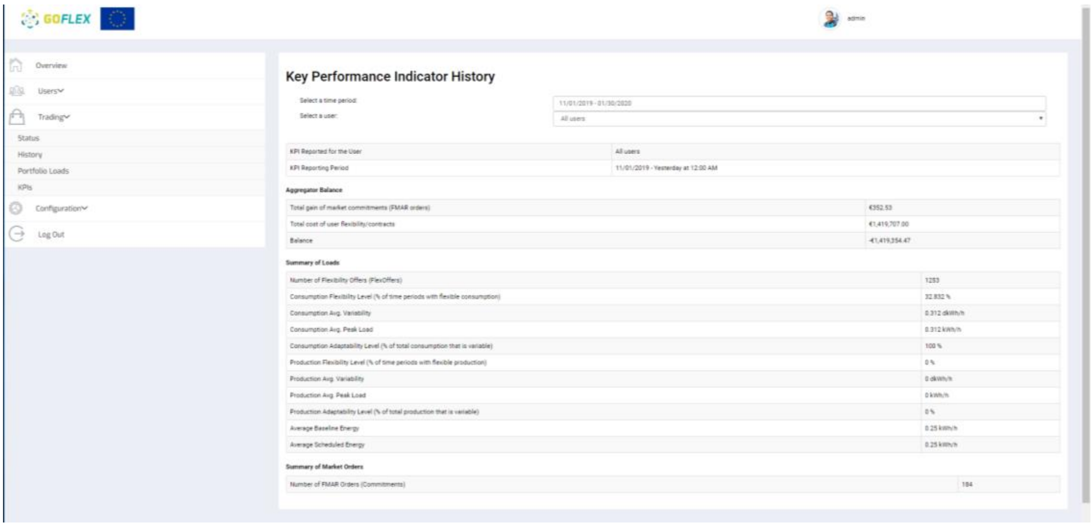
3.4GB / 3.7GB

22.3GB / 291.1 GB

Figure 25: FMAR Performance Snapshot

FMAN's parameter is calculated as depicted in §5.2.2:

$\textit{Consumption Adaptability Level} = \frac{\textit{Consumption Avg.Variability}}{\textit{Average Baseline Energy}}$ * Consumption Flexibility Level (% of time periods with flexible consumption). These parameters are illustrated in Figure 26:



Key Performance Indicator History

Select a time period: 11/01/2019 - 01/30/2020
Select a user: All users

KPI Reported for the User	All users
KPI Reporting Period	11/01/2019 - Yesterday at 12:00 AM

Aggregator Balance

Total gain of market commitments (FMAR orders)	€352.53
Total cost of user flexibility/contracts	€1,419,707.00
Balance	-€1,419,354.47

Summary of Loads

Number of Flexibility Offers (FlexOffers)	1253
Consumption Flexibility Level (% of time periods with flexible consumption)	32.832 %
Consumption Avg. Variability	0.312 dkWh/h
Consumption Avg. Peak Load	0.312 kWh/h
Consumption Adaptability Level (% of total consumption that is variable)	100 %
Production Flexibility Level (% of time periods with flexible production)	0 %
Production Avg. Variability	0 dkWh/h
Production Avg. Peak Load	0 kWh/h
Production Adaptability Level (% of total production that is variable)	0 %
Average Baseline Energy	0.25 kWh/h
Average Scheduled Energy	0.25 kWh/h

Summary of Market Orders

Number of FMAR Orders (Commitments)	184

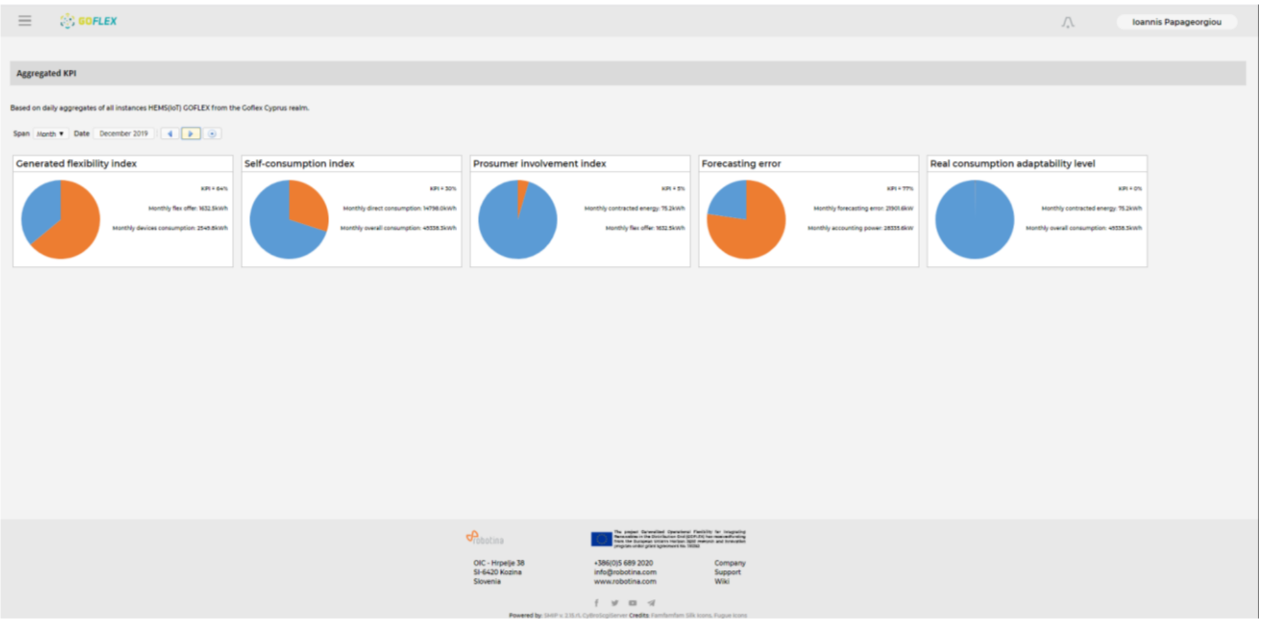
Figure 26: FMAN Performance Snapshot

Metric 4.1.2:

Demand response generated by virtual energy storage in demonstrated use cases in the project

Metric 4.1.2 is calculated at both HEMS and CEMS levels.

At HEMS level it is calculated as "Generated Flexibility Index " as shown in Figure 27.



Aggregated KPI

Based on daily aggregates of all instances HEMS(IoT) GOFLEX from the Goflex Cyprus realm.

Span: Month
Date: December 2019

Generated flexibility index: KPI = 64%; Monthly flex offer: 1632.5kWh; Monthly devices consumption: 2545.8kWh

Self-consumption index: KPI = 30%; Monthly direct consumption: 14798.0kWh; Monthly overall consumption: 45338.3kWh

Prosumer involvement index: KPI = 5%; Monthly contracted energy: 75.2kWh; Monthly flex offer: 1632.5kWh

Forecasting error: KPI = 77%; Monthly forecasting error: 21901.6kW; Monthly accounting power: 28335.6kW

Real consumption adaptability level: KPI = 0%; Monthly contracted energy: 75.2kWh; Monthly overall consumption: 45338.3kWh

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Figure 27: HEMS aggregated performance

As regards the CEMS (EV charging), the load is controllable within the entire range between 0 and maximum possible charging power during the complete duration of charging session. During a certain time period the offered flexibility equals the maximum theoretically achievable consumption (maximum charging power multiplied by duration of time period). If the time available for charging is at least 15% longer than the time needed to charge the EV battery with maximum power (which is usually the case), the goal value of 15% is automatically achieved.

Metric 4.1.3:

Benefit for aggregator

Metric 4.1.3 is calculated by FMAN as depicted in §5.2.2:

$$Aggregator\ Profit = \sum G_{market} - \sum C_{market} - \sum C_{FOS} - \sum C_{fixed}$$

where G_{market} is the sum of market order gains, C_{market} the market order imbalances, C_{FOS} the prosumers rewards and C_{fixed} are fixed costs. Figure 26 provides the referred values where “Total cost of user flexibility/contracts” is C_{FOS} extracted from the prosumers’ contracts. C_{market} are included in parameter “Total Gain of market commitments”.

In the Cyprus case, there is no business case for aggregator related to balancing, therefore C_{market} was set to 0. C_{FOS} has been calculated based on the performance of all delegated (AAU) prosumers (total flexible load 6kW) during November and December 2019 (active operational period). More specifically, the analysis considered the total number of flexible time slots offered and the total time slots actually deviated from the default schedule. A fixed reimbursement of 0.01€ and 0.05€ for each available time slot and shifted time slot respectively was assumed for each prosumer. Similarly, a fixed price of 0.03€ and 0.10€ was set as offered bid price from aggregator for each flexible time slot and each actually shifted time slot respectively. Also, a fixed cost of 2,000€ per year was assumed. In result, the aggregator profit was calculated as follows:

$$Aggregator\ Profit = \text{€}47{,}940 - 0 - \text{€}\,20{,}860 - \text{€}2{,}000 = \boldsymbol{\text{€}25{,}080\,/MW/year}$$

It should be mentioned that this profit could be higher if the number of flexible time slots and actually shifted time slots was higher. On the contrary, this profit assumes that all the market bids were accepted which is not always the case.

Metric 4.1.4:

Lessen the burden of power grids through self-consumption

Metric 4.1.4 is calculated at HEMS for the prosumer and FMAR/DOMS level for the grid.

It is calculated as “Realized consumption adaptability level” in HEMS, as shown in Figure 27. The value achieved (4%) is below the target (15%) due to some issues faced initially on the flexibility procurement side (DOMS requests) that restricted the number of flexibility bids, as well as the winter season that kept usage of some appliances low.

At grid level, Metric 4.1.4 is derived from calculations on other metrics. Derivations yield a potential 28.8%.

Metric 4.1.5:

Increase of prosumer involvement

Metric 4.1.5 is calculated at both HEMS and CEMS levels.

At HEMS level it is calculated as "Prosumer involvement index" as shown in Figure 27. The achieved value (6.25%) is below the target (15%) for the same reasons mentioned at Metric 4.1.4.

CEMS: Due to short time of validation in real environment (the issue is explained in section 5.2) only one offered flexibility was activated. The reasons are the following:

- EV charging is not a continuous process. The actual charging occurs only during few hours a day and the flexibility is available only until the EV batteries are full,
- The activated (contracted) energy doesn't depend only on operation of CEMS. Even if CEMS operates properly, external conditions to trigger the activation of flexibility must exist in operation of the grid.

Obviously, the time periods when the flexibility was available was matching very rarely with time periods when the grid operation conditions required modification of charging load. For this reason, the actual activation of EV charging load flexibility occurred only once. The duration of initial load schedule was 7 time periods; the schedule was shifted for two time periods, resulting in KPI calculated value of 28,5 %.

Metric 4.1.6:

Flexibility range at average occupancy of charging spots

Metric 4.1.6 is calculated at CEMS level.

The KPI is similar to the KPI Demand response generated by virtual energy storage (metric 4.1.2):

- the parameter "Realized avg. consumption" is replaced with "Internal schedule" (scheduled baseload as initially offered by CEMS). Over a certain period of time (duration of charging session), both parameters are equal, because the activation of offered flexibility only modifies the initial load pattern while the delivered energy remains the same;
- the parameter "Offered flexibility" is only split to two parameters (up and down).

The target values (10% for increase of scheduled load - DOWN; 30% for reduction of scheduled load - UP) were achieved due to the nature of EV charging and associated flexibility margins (the entire range of flexibility is available during the complete duration of charging session). A risk for underperformance could occur in the case of clustered charging stations (several chargers supplied via the same supply cable): in this case the power available for charging (rated power of power supply) might not be sufficient to charge all EVs with full power and the achievement of KPI DOWN (increase of scheduled load) could be endangered. In EAC's Use Case, at locations where the chargers were installed such limitation doesn't exist due to strong network (high grid connection power and strong internal – behind the meter – network); as a result, the KPI target values were achieved for both directions of possible energy variation.

Metric 4.1.7:

Flexibility range for varying parking time

Metric 4.1.7 is calculated at CDEMS level but on average instead of varying parking time due to the fact that flexibility was extracted from a virtual electric vehicle (battery storage). As a result CDEMS operation has not been linked to the charging/discharging time, consequently the adaptation potentials are only related to the technical state of charge of the battery. The metric was derived from raw data within the referenced period, yielding a value of 85.75% (downwards) and 173.35% (upwards).

Metric 4.1.8:

Distribution grid stability through responsiveness of flexibility services

Metric 4.1.8 is calculated at DOMS/FMAR level. Derivations on several low-level metrics yield a potential average of 26.4% at 30 minutes timeframe.

Metric 4.1.9

Grid state observability: near-real time (5min) and forecast (forecast 30min up to 24-48 hrs)

The Distribution Observability and Management Service (DOMS) developed in WP4 provides for estimates of the configured state variables over a rolling forecasting horizon of 0 to 24 hours, with a 15-minute interval. DOMS predictions are based on the energy forecasts made available from the IBM Cloud Service Platform (WP5) and are updated continuously as new forecasts become available, typically every hour.

In the case of the Cyprus instance, DOMS configuration included the following 55 state variables:

- Active power load at 15 substations
- Voltage magnitude at 41 connection points of prosumers

The following additional 28 support variables are included in DOMS grid model for Cyprus:

- The active power load of the substation feeders.

DOMS model therefore provides observability for a total of 84 grid points.

This is an example of the observability data returned by the DOMS services, as queried at the time of writing this report:

```
{

  "serviceRequest": {
```

```
    "requestor": "f89855c0-57ed-4d77-bae7-9f58aec87fb9",
    "service": {
      "name": "getObservabilityData",
      "args": {
        "tags": [
          "xest.priority",
          "xest.likelihood"
        ],
        "time_period": {
          "from": "2020-01-23T10:16:24+00:00",
          "to": "2020-01-24T10:16:24+00:00"
        }
      }
    }
  }
}
[
   {
      "timestamp": "2020-01-23T10:30:00+00:00",
      "xest.VOLTAGE_MAGNITUDE_PHA_MAX::11.115": 241.03635306096385,
      "xest.VOLTAGE_MAGNITUDE_PHA_MAX::11.118": 240.93898649878017,
      "xest.VOLTAGE_MAGNITUDE_PHA_MAX::11.135": 236.4495784713824,
      "xest.VOLTAGE_MAGNITUDE_PHA_MAX::11.136": 240.9930655172828,
      "xest.VOLTAGE_MAGNITUDE_PHA_MAX::11.142": 245.18454736139134,
      […]
      "xest.likelihood.VOLTAGE_MAGNITUDE_PHA_MAX::11.115": 1.0,
      "xest.likelihood.VOLTAGE_MAGNITUDE_PHA_MAX::11.118": 1.0,
      "xest.likelihood.VOLTAGE_MAGNITUDE_PHA_MAX::11.135": 0.9999982151781917,
      "xest.likelihood.VOLTAGE_MAGNITUDE_PHA_MAX::11.136": 0.9999999503008145,
      "xest.likelihood.VOLTAGE_MAGNITUDE_PHA_MAX::11.142": 0.9999999999999494,
      […]
      "xest.likelihood.peak::ALAMBRA": 0.999999999021073,
```

```
        "xest.likelihood.peak::DHASOUP": 1.0,
        "xest.likelihood.peak::ERGATES": 1.0,
        "xest.likelihood.peak::FREE INDUSTRIAL ZONE": 1.0,
        […]
        "xest.peak::ALAMBRA": 10794.661366306707,
        "xest.peak::DHASOUP": 33527.330035085084,
        "xest.peak::ERGATES": 6046.479243319533,
        "xest.peak::FREE INDUSTRIAL ZONE": 10918.794827901344,
        […]
        "xest.priority.VOLTAGE_MAGNITUDE_PHA_MAX::11.142": 0.0,
        "xest.priority.VOLTAGE_MAGNITUDE_PHA_MAX::11.159": 0.0,
        "xest.priority.VOLTAGE_MAGNITUDE_PHA_MAX::11.170": 0.0,
        "xest.priority.VOLTAGE_MAGNITUDE_PHA_MAX::11.185": 0.0,
        "xest.priority.VOLTAGE_MAGNITUDE_PHA_MAX::11.195": 1.0,
        "xest.priority.VOLTAGE_MAGNITUDE_PHA_MAX::11.209": 0.0,
        […]
        "xest.priority.peak::PAPACOST": 0.0,
        "xest.priority.peak::RENOS PRENTZAS": 0.0,
        "xest.priority.peak::SEMINARY": 1.0,
        "xest.priority.peak::SOTERA": 0.0,
        "xest.priority.peak::STROVOLO": 1.0,
        "xest.priority.peak::UNIVERSITY": 0.0
    },
    […]
]
```

Figure 28 shows an example of DOMS state variable prediction for the Voltage magnitude on phase C at one of the prosumers. The red- and yellow-shaded areas identify undesired operational ranges, corresponding to “congestions”.

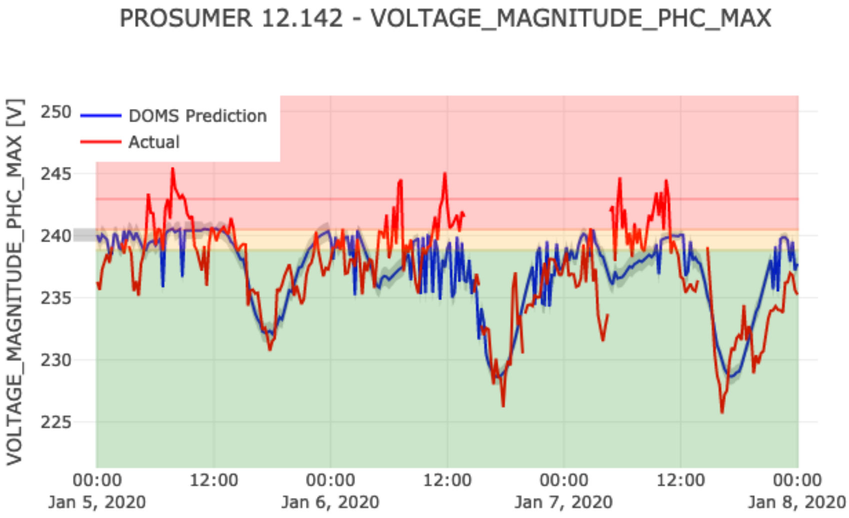


Figure 28: Example of DOMS state variable prediction

Two different metrics were proposed to evaluate the Grid state observability capabilities provided by DOMS:

$$OBSERVABILITY.1 = \frac{Number\ of\ \text{observed}\ state\ variables}{Number\ of\ state\ variables}$$

$$OBSERVABILITY.2 = 1 - \frac{Number\ of\ \text{"metered"}\ variables}{no.\ of\ all\ available\ variables}$$

The KPI “Observability.1” captures the number of observed grid state variables with respect to all possible states of interest (full observability).

An alternative KPI “Observability.2” was introduced to capture the improvement in observability provided by DOMS with respect to raw observations available purely from current system telemetry (e.g. SCADA, metering infrastructure).

Observability.1

Sept 2019: 91.34%

Oct 2019: 93.54%

Nov 2019: 94.90%

Dec 2019: 76.25% ** *(Outage caused missing week in Dec 21-29)*

Jan 2020:94.72%

Total Observability.1 KPI = 88.66%

Observability.2 (Improvement over available metering/scada data)

Sept 2019: 20.62%

Oct 2019: 28.69%

Nov 2019: 29.75%

Dec 2019: 26.62%

Jan 2019: 32.54%

Total Observability.2 KPI = 27.01%

Metric 4.1.10:

Likelihood of Prediction of congestion (voltage/power-flow limit violation)

Along with the prediction estimates of the configured state variables, DOMS software predicts the likelihood that any of the state variables is in an undesired operational range, with respect to the user-defined tolerance levels.

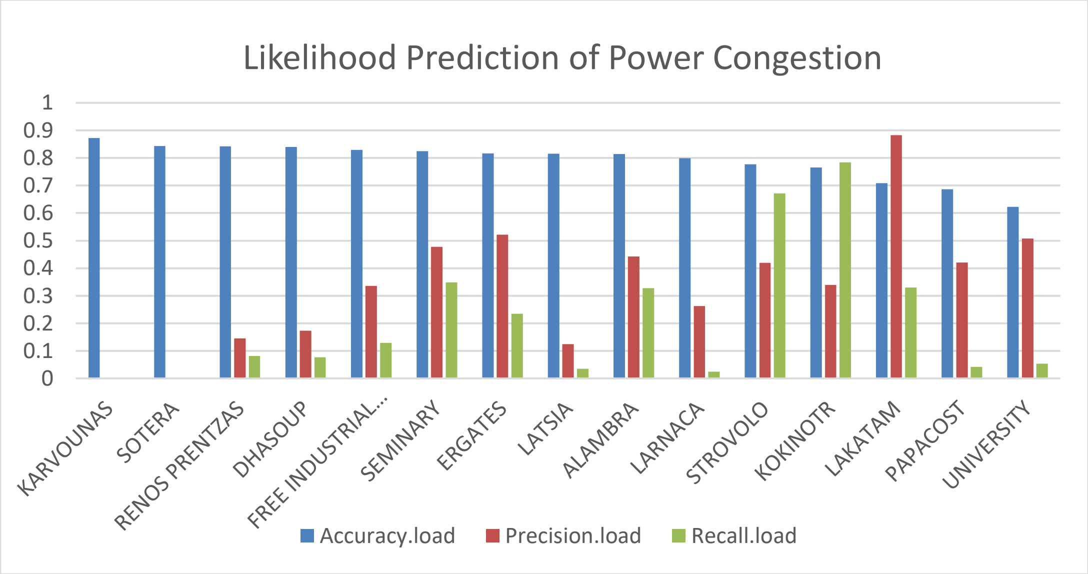
The performance of DOMS congestion predictions is evaluated using typical classification metrics of Precision, Accuracy and Recall:

$$ACCURACY = TP + TN$$

$$PRECISION = \frac{TP}{TP + FP}$$

$$RECALL = \frac{TP}{TP + FN}$$

Based on true-positive (TP), true-negative (TN), false-positive (FP) and false-negative (FN) rates of the predictions of undesired state variable operational ranges. A breakdown of the Accuracy metric between power and voltage likelihood of congestions, observed during trial operations is shown in Figure 29



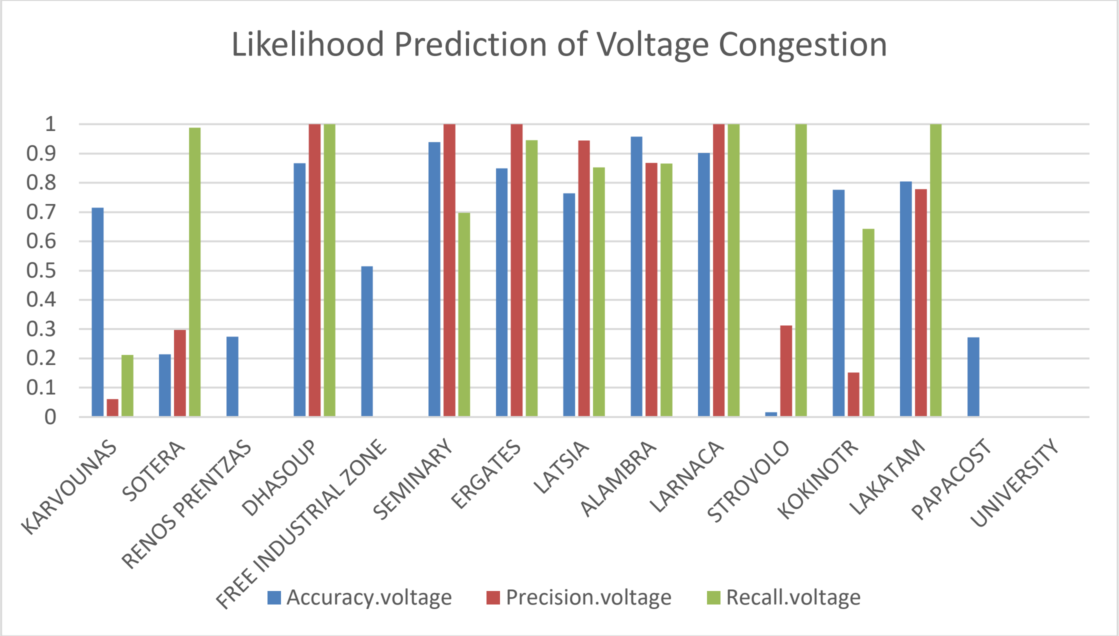


Figure 29: Accuracy metric between power and voltage likelihood of congestions

We use Accuracy to summarise the performance of DOMS congestion predictions, since it combines both true positives and true negatives, breaking down the value by active power and voltage congestions:

Accuracy.load = 79.02%

Accuracy.voltage = 70.95% ** *(excluding RENOS PRENTZAS, FREE INDUSTRIAL ZONE, UNIVERSITY)*

Total Accuracy = 74.99%

Metric 4.1.11:

Accuracy of forecasts at prosumer, MV/LV transformer or substation level (energy demand, generation, flexibility):

Prosumer level:

It is calculated at HEMS level. The value achieved (25.25%) is higher than the target (10%) due to unpredictable nature of the flexible user appliances.

S/S level:

Several modelling techniques were used to generate forecasts for the GOFLEX demonstrations. GAM (1), Sarima (2) and MLP (3) were used as was an ensemble technique which combines all three.

The MAPE (4) calculation was used to determine the accuracy of the forecasts generated.

Table 4: MAPE at forecast horizon

		MAPE (%) at forecast horizon		
Entity	**Signal**	**1-hour**	**6-hour**	**12-hour**
FREE INDUSTRIAL ZONE	ENERGY_LOAD	1.05	10.86	10.86
RENOS PRENTZAS	ENERGY_LOAD	17.03	10.76	10.78
ALAMBRA	ENERGY_LOAD	6.89	6.98	7.09
DHASOUP	ENERGY_LOAD	9.74	9.84	9.86
ERGATES	ENERGY_LOAD	7.21	7.41	7.59
KARVOUNAS	ENERGY_LOAD	8.85	8.97	8.85
KOKINOTR	ENERGY_LOAD	6.89	12.83	13.04
LAKATAM	ENERGY_LOAD	12.60	16.61	16.59
LARNACA	ENERGY_LOAD	9.36	9.37	9.39
LATSIA	ENERGY_LOAD	11.81	11.78	11.75
PAPACOST	ENERGY_LOAD	11.94	12.00	11.96
SEMINARY	ENERGY_LOAD	7.75	8.05	8.51
SOTERA	ENERGY_LOAD	8.23	9.42	9.41
STROVOLO	ENERGY_LOAD	8.59	8.58	8.81
UNIVERSI	ENERGY_LOAD	4.48	15.62	15.64
Average	ENERGY_LOAD	8.83	10.61	10.68

Table 5: Scaling KPIs

Quantity	Target Value	Metric
Total Time Series	n/a	1,872
Total Time Series (Observed)	n/a	476
Total Time Series (Forecast)	n/a	1,396
Total Data Points	n/a	483,061,676
Total Data Points (Observed)	n/a	111,946,877
Total Data Points (Forecast)	n/a	371,114,799
Total Trained Models	n/a	212

Table 6: Platform KPIs

Quantity	Target Value	Metric
Accuracy of forecasts at substation level	<10%	8.83% ✓
Accuracy of forecasts at BRP level	<5%	n/a
Service platform query response time	< 1 minute	3.5 seconds ✓
Service platform availability of observations	< 5 minutes	0.4 seconds ✓
Service platform availability of next forecast update	< 30 minutes	26 seconds ✓

Non-trackable KPIs:

Capable of integrating large share of RES

The amount of RES that can be connected to a power system is strongly related to the location of the connection. More specifically, is related to the system impedance (R and X) at the point of the connection. In order to check the increase of RES penetration due to GOFLEX, EAC performed simulations using DIgSILENT PowerFactory software. The network that was examined was the University Primary Substation and the single line diagram used is presented in Figure 30. Load profile curves used in the simulations were obtained from the Energy Management System – SCADA.

Methodology

Initially the network of the University of Cyprus was modelled in DIgSILENT Power Factory. By utilizing historical load profile curves the load of each distribution Substation was modelled. Afterwards the initial Hosting Capacity of each distribution Substation was evaluated. Hosting Capacity is defined as the amount of RES that can be connected to a specific Busbar (location) without violating any operational limit. The operational limits were defined according to the current Cyprus Grid Code and the Technical Manual for connection of RES and there are as follow:

Maximum Busbar Voltage Variation before and after DER connection = 2%
Maximum Voltage Deviation +10%
Minimum Voltage Deviation -10%
Maximum Branch Element Loading = 100%
For the pilot site of Cyprus, only PV penetration was examined as is the most economically efficient RES technology. The inverters of the PVs were modelled with the active power – power factor mode.

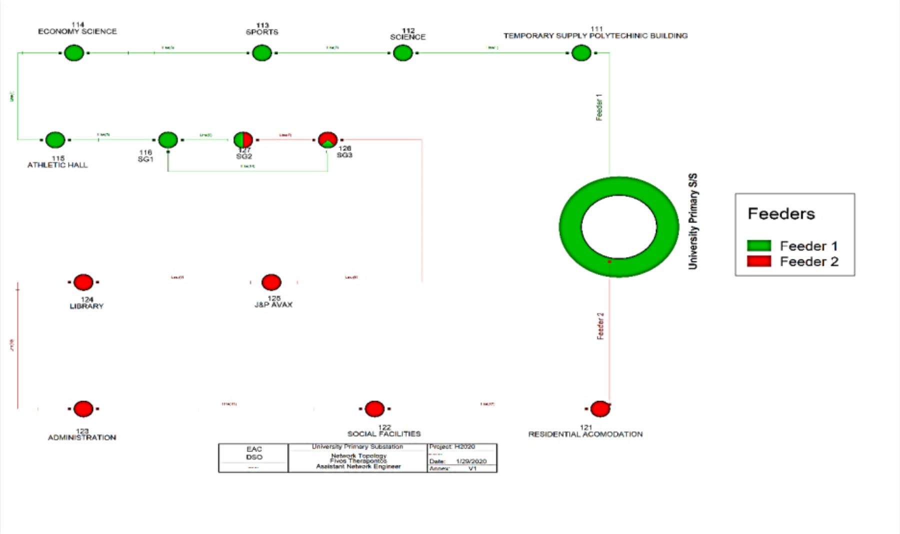


Figure 30: Single Line Diagram of University of Cyprus modelled in DIgSILENT

Hosting Capacity Analysis

Figure 31, presents the results of the Hosting Capacity performed with the initial loading conditions. It can be seen that, on average 6.3MW can be connected on each Distribution Substation.

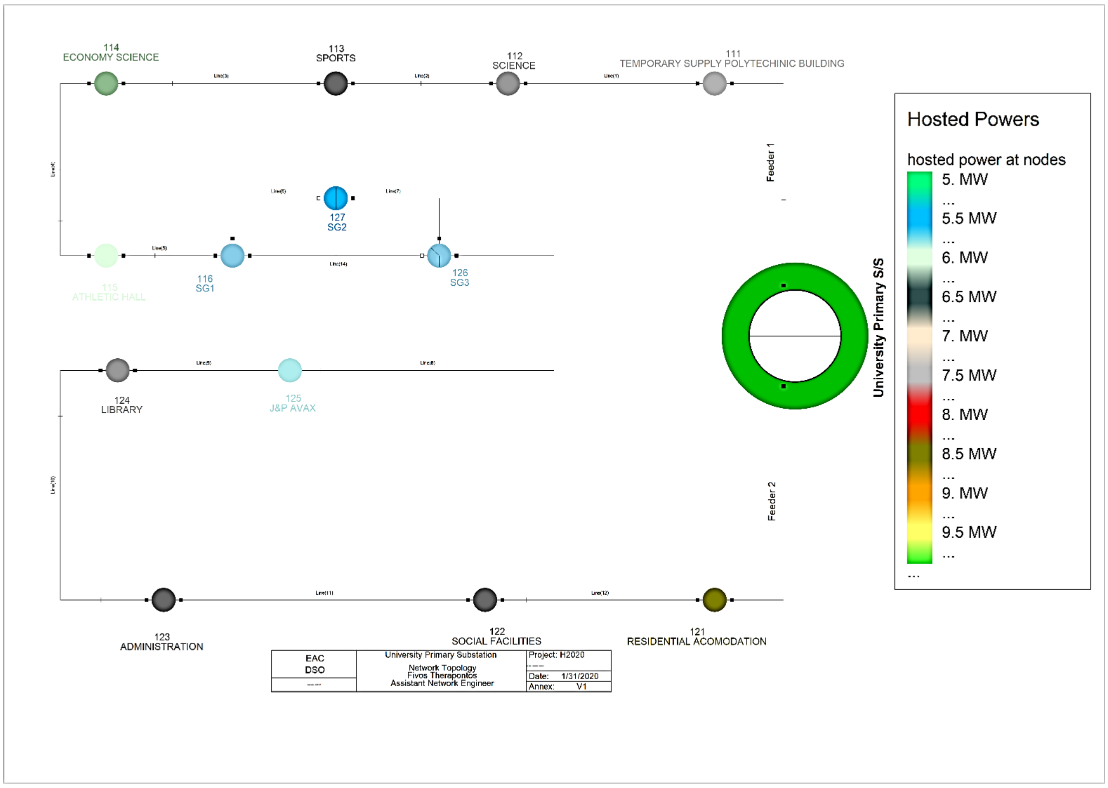


Figure 31: Initial Hosting Capacity

In addition, load shift was applied to the Loads of the Buldings that BEMS were installed. Figure 32, presents the load shift applied to the distribution Substation Library. It can be seen that approximately 15% of the total load was shifted (delayed) for one hour. This methodology was applied to all the 4 BEMS.

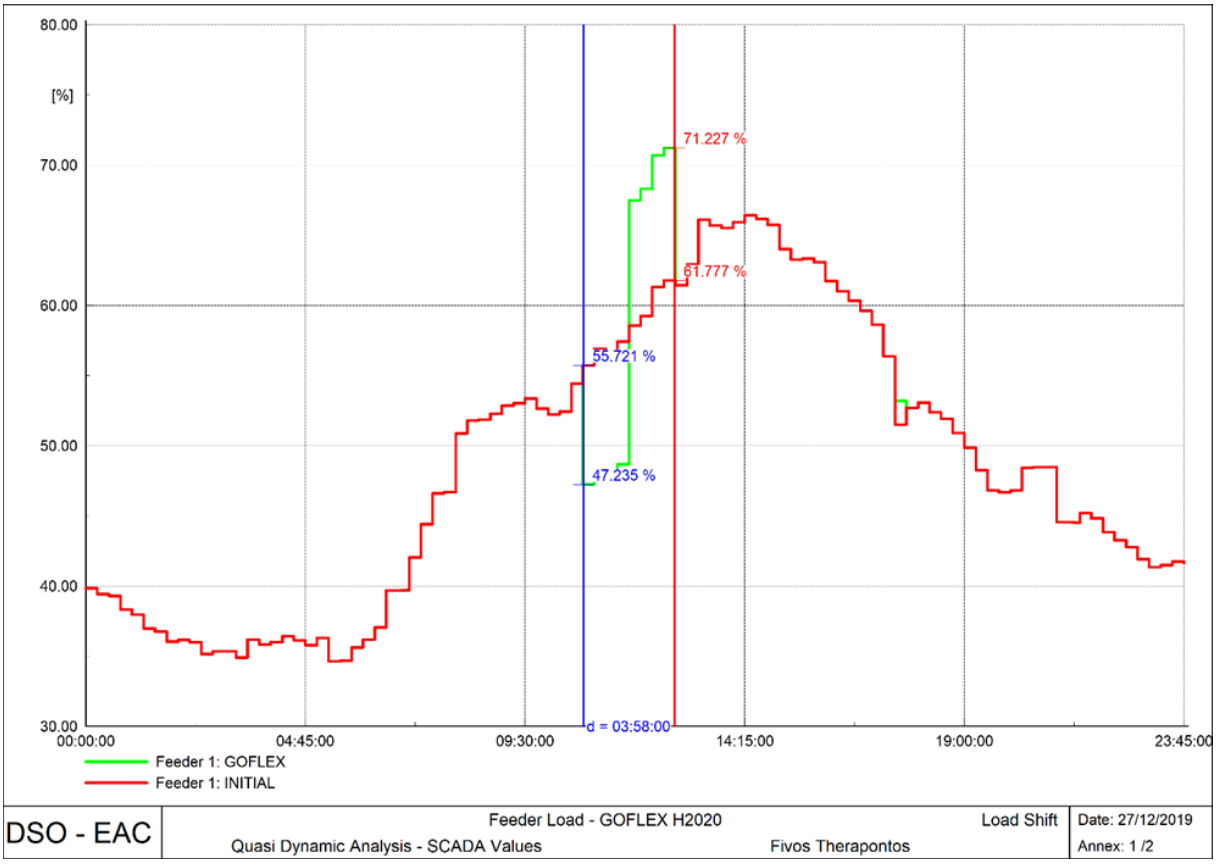


Figure 32: Load Shift - GOFLEX Solution

Afterwards, the new increased Hosting Capacity was evaluated and the results are listed in Table 7. Hosting capacity of Distribution Substations that BEMS were not installed remained unchanged, while for the 4 BEMSes Hosting capacity has increased.

Table 7: Safe increase of RES penetration

BEMS	Feeder	Initial Hosting Capacity (MW)	GOFLEX Hosting Capacity (MW)	Hosting Capacity Increased (MW)	Hosting Increase (%)
1	2	6.405	7.532	1.127	17.596%
2	1	6.400	7.380	0.980	15.313%
3	2	6.405	7.547	1.142	17.830%
4	2	8.445	9.759	1.314	15.560%

As can be seen in Table 7, the safe increase of RES penetration has increased in all the Substations where BEMS were installed. The average increase observed was 16.58% with an average active power increase of 1.141MW.

Benefit for DSO

From the results of the Cost-Benefit analysis (Section 5), GOFLEX yields a NPV of €9,687,578 for EAC(DSO) when a Peak Demand Reduction of 15.66% is achieved. The average Peak Demand of Cyprus power system is approximately 1000MW, therefore an equivalent 156.6MW (15.66%) reduction of peak demand results to €9,687,578 savings for congestion management. Consequently, the benefit for DSO for each 1MW peak demand reduction is 61,862€/MW. This value is significantly lower than the target value due to the fact that ancillary services as frequency containment reserves (FCR) and frequency restoration reserves (FRR) can only be procured and estimated by Cyprus TSO.

Avoid congestions: reduction of peak demand

Due to the fact that the number of GOFLEX prosumers is only a very small fraction of the total number of customers, projections were necessary to get meaningful values. Initially we examined a specific MV feeder where two GOFLEX prosumers are connected. Then we compared the predicted peak demand of the feeder from DOMS to the measured peak demand of the feeder from SCADA-EMS. Then we divided the measured peak demand reduction with the percentage of GOFLEX users to the actual feeder users. In result, as seen from Table 8, a Peak Demand Reduction Factor of 15.66% was estimated.

Table 8: Parameters exploited for peak demand reduction KPI

Predicted Peak Demand of The Feeder (DOMS)	9.5 MW
Number of Costumers per MV Feeder	700
Realized Flexibility of Feeder (FMAR)	0.00425 MW
Measured Peak Demand of Feeder (SCADA EMS - EAC)	9.49575 MW
Number of GOFLEX Users at the Feeder	2
Percentage of GOFLEX Users to Total Costumers	0.29%
Peak Demand Reduction Realized	0.04%
Peak Demand Reduction Factor	**15.66%**

4.3 Summary Performance Evaluation

We evaluated performance as described above. The results are summarized in the following table.

Table 9: Results of performance metrics for GOFLEX Demonstration in Cyprus

Project Performance Indicator (order of appearance in DoA)	Trackable KPIs	Explanation	Targets	Results
Electricity load adaptability level	4.1.1 Electricity load adaptability level	The maximum energy variation of loads over the maximum energy consumption, in an hour. The degree that loads can vary their consumption.	>15%	**FMAR 32,4%** **FMAN 40,97%**
DR generated by virtual energy storage in demonstrated use cases	4.1.2 Demand response generated by virtual energy storage in demonstrated use cases in the project (during 3 months' testing & evaluation period)	Energy demand variation with respect to peak demand. The real flexibility offered by controllable loads.	>15%	**64%** **CEMS:** far beyond the target value due to the fact that maximum flexibility is available during the complete duration of charging session
Benefit for aggregator	4.1.3 Benefit for aggregator	Profit for Aggregator per MW scheduled, over a year	>€35,000/MW/year + €200/MWh	**€25,080 /MW/year** (MWh is only applicable to balancing scenario)
Lessen the burden of power grids through self-consumption	4.1.4 Lessen the burden of power grids through self-consumption	Level of delivered flexibility over overall consumption / peak consumption (HEMS / grid level)	>10%	**HEMS 4%** **FMAR 28.8%**
Increase of prosumer involvement (Augmented DR)	4.1.5 Increase of prosumer involvement	Percentage of activated flexibility over all offered flexibility	>15%	**HEMS: 6,25%** **CEMS: 28.5%**
Flexibility range at avg occupancy of charging spots	4.1.6 Flexibility range at average occupancy of charging spots	Energy demand variation with respect to peak demand for the average occupancy. The real flexibility offered by controllable loads.	10 / -30 %	**CEMS:** Far beyond the target values due to the fact that flexibility is available either in "+" or "-" direction during the complete duration of charging session
Flexibility range for varying parking time	4.1.7 Flexibility range for varying parking time	Energy demand variation with respect to peak demand for 2hrs and 8hrs occupancies. The real flexibility offered by controllable loads.	2 hours: +/- 10%	**-85.75%** **+173.33%**
			8 hours: +/- 25%	
Distribution grid stability through responsiveness of flexibility services	4.1.8 Distribution grid stability through responsiveness of flexibility services	Delivered flexibility over requested flexibility in different time frames	30 min (25% of DR)	**26.4%**
Grid state observability	4.1.9 Grid state observability: near-real time (5min) and forecast (forecast 30min up to 24-48 hrs)	# of observed state variables over all state variables.	>80%	**88.66%**
Likelihood of prediction of congestion	4.1.10 Likelihood of Prediction of congestion (voltage/power-flow limit violation)	Frequency of correct prediction of occurrence of congestion	>90%	**74.99%**

Project Performance Indicator (order of appearance in DoA)	**Trackable KPIs**	**Explanation**	**Targets**	**Results**
Accuracy of forecasts at prosumer, T/R, S/S level	4.1.11 Accuracy of forecasts at prosumer, MV/LV transformer or substation level (energy demand, generation, flexibility)	MAPE of forecasts at prosumer and S/S level	<10%	**25.25%/ 8.83%**
Latency/efficiency of data querying	4.1.13 Latency / efficiency of data querying	SP responsiveness to data querying	< 1 minute	**3.5 seconds**
Latency/efficiency of data querying			< 5 minutes	**0.4 seconds**
Latency/efficiency of data querying			< 30 minutes	**26 seconds**
Capable of integrating large share of RES	-	The % increase in RES penetration owed to flexibility procurement. Computed for UCY campus	>15 %	**16.58%**
Benefit for DSO	-	The monetary benefit from DSO derived from flexibility procurement in the grid congestion scenario.	€1M / MW	**61,862€/MW**
Avoid congestions: reduction of peak demand	-	The difference between Peak demand expected - Peak demand realized	>15%	**15.66%**

With regards to the Business KPIs, the following figures are extracted from FMAR or derived from further calculations:

Table 10: Business KPIs Evaluation

Business KPIs	SERVICE	Value achieved
1.1: Number of flexibility offers traded with the DSO: 10 flexibility offers/day	**Microgrid offering flexibility to the DSO**	**11.16**
1.2: Activation of demand response strategies through the BEMS: 10/day		**11.16**
1.3: Reduction of the total cost of electricity: 20% reduction compared with the current situation		**25.78%**
2.1: Number of flexibility offers traded with the DSO: 10 flexibility offers/day	**Prosumers offering flexibility to the DSO**	**23.5**
2.2: Activation of demand response strategies through the HEMS/Controllable load: 10/day		**23.5**
2.3: Reduction of the total cost of electricity: 10% reduction compared with the current situation		**11.12%**
4.1: Number of activated flexibility offers for grid congestion relief: 5 offers /day	**Grid congestion relief**	**26.5**
4.2: Reduction in the total cost of new grid infrastructure: 20% reduction		**36.8%**

All the Business KPIs except from 1.3, 2.3, and 4.2 have been derived from FMAR (Performance- Build report- VPP Hierarch Report) from tracked parameters for the active operational period (November to December 2019).

Business KPI 1.3: Using the recorded flexibilities during the trading period between November to December 2019 coming from the 4 BEMSs that were connected to the GOFLEX ATP we have identified high correlation with the flexibilities generated by the active prosumers since these are related to cooling and heating needs only. No other flexibility was available at the university campus over that trading period. Using this correlation, we can safely deduce that corresponding benefits are recorded as with the rest of the prosumers. Using the estimated trading benefits of the DSO of Cyprus giving the financial benefits of €0.01 for availability and €0.05 for every 15 minute applied time shift for every available flexible kW for the benefit of prosumers and the equivalent of €0.03 for availability and €0.1 for every 15 minute applied time shift for every available flexible kW for the benefit of aggregators as is the case of the university who acts with both roles prosumer and aggregator, the overall cost of electricity reduction is estimated to be 25.78% which is above the targeted figure of 20%. This figure is evaluated using the recorded implementation of nominated flexibilities from the records of the DSO. Out of every 100 nominated flexibilities 30% are implemented and 70% just available but not implemented.

Business KPI 2.3: was calculated by diving the total monetary reimbursements of each GOFLEX user compared to their electricity bill in the same period. The examined period was from November to December of 2019. An average 11.12% reduction of the total cost of electricity was calculated. It should be noted that the bimonthly electricity bill of all the GOFLEX users was relatively low due to the fact that they each user has a 4kWp PV installed.

Business KPI 4.2: has been calculated based on the results of Cost-Benefit Analysis (§5). More specifically, we divided the expected grid CAPEX savings from GOFLEX (€23,278,009) to the total EAC Grid Investments costs for Congestion Avoidance (€63,222,875).

5 Cost Benefit Analysis

5.1 DSO congestion avoidance

For EAC(DSO), GOFLEX Platform is expected to be used mainly for congestion avoidance. It should be noted that reducing or eliminating congestions will have also a beneficial effect on voltage stability. In order to evaluate the economic viability of GOFLEX Solution, initially EAC calculated all the expected grid investments for Congestion Avoidance for the period 2020-2034 which is defined as the Business as Usual case (BaU). Afterwards, we estimated the expected grid investments reductions with GOFLEX by utilizing the KPIS obtained during the operational period. In addition, all the costs associated with GOFLEX have been compared with the expected grid investments for congestion avoidance. Finally a sensitivity analysis has been performed to verify that GOFLEX Platform is economically beneficial for EAC (DSO). For the calculations of net present values of all cash flows a discount rate of 1.5% has been applied.

5.1.1 Calculation of EAC Grid Investments for Congestion Avoidance

Initially, EAC calculated the expected grid investments costs for the period 2020-2034, based on the 10 year Development Plan for the Distribution System. As it can be seen from Table 11, the total expected investments during the period 2020-2034 are €570,746,581 (Net Present Value = €498,923,574). The grid investments are calculated only for the MV and LV Overhead Lines, MV and LV Underground Cables and for distribution substations.

Table 11: EAC (DSO) Grid Investments 2020-2034

Year	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
MV U/H	4,971,450	5,123,250	5,252,280	5,381,310	5,510,340	5,631,780	5,760,810	5,889,840	6,018,870	6,147,900	6,276,930	6,276,930	6,276,930	6,276,930	6,276,930
MV O/H	1,062,298	1,405,413	1,746,589	2,087,765	2,428,941	2,770,117	3,113,231	3,454,407	3,795,583	4,136,759	4,479,874	4,838,263	5,225,324	5,643,350	6,094,818
LV U/G	5,942,200	5,875,600	6,471,300	7,067,000	7,662,700	8,258,400	8,850,400	9,446,100	10,041,800	10,637,500	11,233,200	11,794,860	12,384,603	13,003,833	13,654,025
LV O/H	1,482,355	1,552,670	1,622,985	1,694,735	1,765,050	1,835,365	1,905,680	1,975,995	2,046,310	2,116,625	2,188,375	2,254,026	2,321,647	2,391,296	2,463,035
PM Transformers	603,272	851,192	1,090,848	1,289,184	1,479,256	1,702,384	2,008,152	2,223,016	2,446,144	2,661,008	2,892,400	3,123,792	3,373,695	3,643,591	3,935,078
GM Transformers	7,943,820	8,929,100	9,914,380	10,714,920	11,638,620	12,685,480	14,286,560	15,333,420	16,318,700	17,303,980	18,289,260	19,203,723	20,163,909	21,172,105	22,230,710
All	22,005,395	23,737,225	26,098,382	28,234,914	30,484,907	32,883,526	35,924,833	38,322,778	40,667,407	43,003,772	45,360,039	47,491,595	49,746,109	52,131,106	54,654,597

Table 12, summarizes the congestion factors for each equipment type. Congestion factor (C) is the percentage of the equipment that is expected to be replaced/reinforced due to congestion. These factors have been estimated by EAC based on historical data and the 10 year Cyprus Load Forecast of Cyprus TSO.

Table 12: Congestion Factors

Equipment Type	Congestion Factor (C)
MV U/H	11.00%
MV O/H	30.00%
LV U/G	9.00%
LV O/H	27.00%
PM Transformers	18.00%
GM Transformers	9.00%

Based on the congestion factors and the total expected Grid Investments, the total investment cost due to congestions has been estimated to €72,417,993 (Net Present Value= **€63,222,875**) which is approximately 12.6% of the total investments.

5.1.2 Calculation of Grid Investment Reduction with GOFLEX

Furthermore, based on the KPIs calculated during the operational period, EAC estimated the expected grid investment reduction by utilizing GOFLEX. More specifically, during operational period KPI Peak Demand Reduction has been estimated to be approximately **15%.** Reduction in system peak demand is expected to reduce the number of congestions in the Distribution Network. In order to evaluate the number of congestion reduction the Average Peak Responsibility Factor has been introduced. Average Peak Responsibility factor (R) can be calculated with the next equation, and is the ratio of the loading of the equipment during system peak period to the peak load of equipment. Since R is directly related with system Peak Demand, it can be used to estimate the effect of system Peak Demand to the equipment loading.

$$R = \frac{Load\ of\ Equipment\ during\ System\ Peak}{Peak\ Load\ of\ Equipment}$$

Afterwards, by utilizing the following equation, which relates the Peak Demand Reduction with the Congestion Factor and R, the adapted congestion factors for each equipment type has been evaluated as can be seen in Table 13.

$$Adapted\ Congestion\ Factor = (1 - \text{Peak}\ Demand\ Reduction) * C * R$$

Table 13: EAC Peak Responsibility Factor and Congestion Factors

Type of Equipment	Average Peak Responsibility Factor (R)	Adapted Congestion Factor
MV U/H	75.0%	7.01%
MV O/H	80.0%	20.40%
LV U/G	69.0%	5.28%
LV O/H	75.0%	17.21%
PM Transformers	77.0%	11.78%
GM Transformers	72.0%	5.51%

By utilizing the Adapted Congestion Factor in the methodology used in section 5.1 the Grid Investment Reduction has been estimated in the proposed GOFLEX scenario. The expected grid investment costs with GOFLEX Platform have been reduced to €45,762,813 (**Net Present Value = €39,944,866**), therefore **€23,278,009** are expected grid CAPEX savings compared to the BaU.

5.1.3 Calculation of Expected Flexibility Energy Units

In Cyprus, congestions in MV and LV Equipment are expected due to the two following reasons:

1) Winter Case: Increased Demand (Load) combined with low RES generation. This situation is expected during night hours, mainly due to EVs and in winter months where the RES generation is relatively low while electricity is heavily being utilized for heating.
2) Autumn Case: Increase Generation from RES combined with low demand. This situation is expected in autumn where the generation from RES is approximately maximum while demand is minimum.

Based on historical data measurements from Energy Management System SCADA, we have identified the feeders that have the highest utilization percentage compare to the existing load curves, thus the higher net load and consequently are more likely to be congested. In addition, by utilizing the forecasted load profile curves and peak demand predictions we were able to identify the number of feeders that are expected to be congested over the period 2020 to 2034. Afterwards, we calculated the Flexibility Energy units that will be procured in order to avoid congestion based on winter and autumn case (Table 14**,** Table 15).

- Num. Of Feeders with Overload: Calculated based on the Percentage of current feeder loading and future peak demand

- Num. of Days with Overload: Calculated based on Historical data, (i.e number of days of High Demand Combined with low RES generation) and predicted load curves (TSO)
- Num. Of Hours of Overload: Calculated based on Predicted load curves and future prediction of peak demand
- Requested Power Reduction per Feeder: Evaluated based on current feeder loadings and the predicted load profiles. This value is limited to 2.5MW which is the additional power rating of the $70mm^2$ Cu line compared to $32mm^2$ Cu.

Based on the results of the analysis the total Flexibility Energy Units that EAC is expected to procure over the next 15 years are 71273.64MWh.

Table 14: Expected Congestion 2020-2034 (Winter Case)

Expected Congestion 2020 -2034 (Winter Case)															
Year	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Num. Of Feeders with Over-load	5	5.75	6.61	7.60	8.75	10.06	11.57	13.30	15.30	17.59	20.23	22.66	22.93	23.20	23.48
Num. of Days with Overload	8	9.20	10.76	12.59	14.73	17.24	20.17	23.60	24.19	24.79	25.41	26.05	26.70	27.37	28.05
Num. Of Hours of Overload	1	1.18	1.39	1.64	1.94	2.29	2.70	3.19	3.76	4.44	5.00	5.00	5.00	5.00	5.00
Power Reduction Per Feeder (MW)	0.5	0.70	0.90	1.02	1.10	1.22	1.35	1.50	1.60	1.75	2.00	2.15	2.25	2.50	2.50
Total Energy Reduction (MWh)	20	43.70	89.20	160.5	274.81	483.9	850.1	1499.7	2225.1	3385.1	5140.7	6344.1	6886.8	7937.5	8233.5

Table 15: Expected Congestion 2020-2034 (Autumn Case)

Expected Congestion 2020 -2034 (Autumn Case)															
Year	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Num. Of Feeders with Overload	2	2.40	2.88	3.46	4.15	4.98	5.97	7.17	8.60	10.32	12.38	14.86	17.83	21.40	25.68
Num. of Days with Overload	5	5.75	6.56	7.47	8.52	9.71	11.07	12.84	14.90	17.28	20.05	23.25	26.97	31.29	36.30
Num. Of Hours of Overload	0.5	1.18	1.39	1.64	1.94	2.29	2.70	3.19	3.25	3.41	3.58	3.76	3.95	4.15	4.36
Curtailment Per Feeder (MW)	0.25	0.50	0.75	1.00	1.10	1.25	1.30	1.55	1.65	1.70	1.85	2.00	2.15	2.35	2.50
Total Energy Reduction (MWh)	1.25	8.14	19.71	42.43	75.35	138.21	232.03	454.42	687.0	1034.5	1645.5	2600.1	4085.3	6526.5	10148

According to the loading conditions of each feeder, Flexibility can be categorized as follows:

- **Critical Flexibility (CF)** occurs when a feeder is congested more than **120%** of its nominal capacity.
- **Normal Flexibility (NF)** is requested when the loading of the feeder is between **105% to 120%** of the nominal feeder capacity.
- **Non Critical Flexibility (NCF)** is requested when the Feeder is expected to be loaded between **95-105%.**

During Operational Period, several flexibility procurements from EAC occurred. Table 16, presents the percentages of each Flexibility Type occurrence to the total number of violations for each Substation. Based on the Substation Capacity (MW), the weighted average of each Flexibility type has been estimated as shown in Table 16 for the whole system. Table 17, second column, introduces the cost for each Flexibility Type that has been previously estimated internally be EAC (DSO) for future procurement of Flexibility. The cost of each Flexibility Type has been calculated with the following equation:

Table 16: DOMS results during operational period

Substation	**Capacity (MW)**	**NCF**	**NF**	**CF**
Alambra	54	37.51%	51.59%	10.90%
Dhasoupoli	120	65.37%	4.15%	3.11%
Ergates	63	51.30%	9.93%	9.56%
Lakatamia	80	22.56%	92.88%	0.00%
Renos Prentzas	120	61.22%	7.93%	2.45%
Papacostas	94.5	7.41%	3.73%	0.00%
Sotera	63	100.00%	0.00%	0.00%
Karvounas	30	98.11%	0.07%	0.00%
Latsia	80	14.20%	10.30%	0.00%
Seminary	111.5	19.77%	95.18%	1.11%

Strovolos	94.5	18.99%	226.39%	0.00%
FIZ	63	66.96%	2.89%	2.67%
Larnaka	94.5	64.64%	3.11%	1.63%
Kokkinotrimithkia	63	35.58%	98.74%	17.35%

$$\begin{aligned} &Cost\ of\ Flexibilty\ Type \\ &\qquad = Cost * Percentage\ of\ occurrance * Total\ Flexibility\ Energy\ Units \end{aligned}$$

Table 17: Flexibility Type - Cost - Occurrence

Type of Flexibility	Cost (Euro/MWh)	Percentage of occurrence	Cost 2020-2034
Critical Flexibility	157.99	8%	897,463
Normal Flexibility	110.67	45%	3,520,349
Non Critical Flexibility	94.54	47%	3,193,911

Consequently, the estimated cost for the Flexibility energy units that will be procured by EAC in order to avoid congestion are €7,611,724 (Net Present Value= **€6,306,725**)

5.1.4 GOFLEX Platform Expenses

Operational Expenses (OPEX) of the GOFLEX Platform have been estimated to be €2,284,711.48 (Net Present Value), with the assumptions of 4 operators with an average annual wage of €40,000.00 and 1% wage increase rate for 15 years of operation. The Capital Expenses (CAPEX) of the Platform have been estimated to be €5,000,000. Table 18, summarizes all the associated costs of the GOFLEX Solution.

Table 18: GOFLEX Costs

GOFLEX Costs (€)	
CAPEX	5,000,000
OPEX Personnel	2,284,711
Market Reimbursements	6,306,725
Total Cost	13,591,436

Weighing the costs (€13,591,436) and benefits (€23,278,009) from GOFLEX yields a CBA NPV value of €9,686,573 over a 15-year horizon.

5.1.5 Sensitivity Analysis

In order to evaluate if the GOFLEX Solution is economically viable, a sensitivity analysis has been performed. The results of the analysis shown in Table 19, clearly indicates that the GOFLEX Solution is economically viable in all cases. In the analysis, the factors that are related with the GOFLEX costs have increased and the Peak Demand Reduction (KPI) has decreased to check only the negative case scenarios. In conclusion, GOFLEX Solution is economically beneficial for EAC.

Table 19: Sensitivity Analysis Results

Factors (€)	2.5%	5%	7.5%	10%
Market Reimbursement (Increase)	9,528,905	9,371,237	9,213,568	9,055,900
Peak Demand Reduction (Decrease)	8,511,724	7,336,875	6,162,026	4,987,177
GOFLEX CAPEX (Increase)	9,561,573	9,436,573	9,311,573	9,186,573
GOFLEX OPEX (Increase)	9,629,455	9,572,337	9,515,219	9,458,102
Flexibility Prices (Increase)	9,528,905	9,371,237	9,213,568	9,055,900

5.2 University Microgrid offering flexibility to the DSO

5.2.1 Introduction

This section documents the economical evaluation of the pilot energy community at the University of Cyprus (UCY) as an integral component of the University microgrid that will incorporate at the complete stage 10 MWp of PV plant and 7.5 MWh of battery storage.

The target is to transform the large campus of University of Cyprus into a self-consumption controllable microgrid, which will be fed by PV and central and distributed energy storage systems. The campus microgrid will be able to operate either grid-connected, offering at the same time the possibility for ancillary services to the DSO, or isolated in case of a grid fault or other operational necessities. In order to design the campus microgrid, initial simulation tests will be carried out by using commercial software. During the simulation work, exhaustive tests on the current status of the system complemented with new equipment purchased through ongoing projects external to GOFLEX but also the ones purchased through GOFLEX

5.2.2 Economic benefits through trading of flexibility

As shown in figures 33 and 34 below, the University of Cyprus acted in the GOFLEX project as an aggregated load offering flexibilities to the local DSO to meet grid congestion issues of the grid. Adapting the same cost and benefit methodology as the DSO above, the traded flexibility benefits can offer added benefits to the university capable of reducing the overall energy cost of the university.

Thus, as already indicated in previous paragraphs, by using the recorded flexibilities during the trading period between November to December 2019 coming from the 4 BEMSs that were connected to the GOFLEX ATP it was identified that there is high correlation with the flexibilities generated by the active prosumers since these are related to cooling and heating needs only. No other flexibility was available at the university campus over that trading period. Using this correlation, it is safely deduced that corresponding benefits are recorded as with the rest of the prosumers. Using the estimated trading benefits of the DSO of Cyprus giving the financial benefits of €0.01 for availability and €0.05 for every 15 minute applied time shift for every available flexible kW for the benefit of prosumers and the equivalent of €0.03 for availability and €0.1 for every 15 minute applied time shift for every available flexible kW for the benefit of aggregators as is the case of the university who acts with both roles prosumer and aggregator. Using these figures, the overall cost of electricity reduction is estimated to be 25.78% which is above the targeted figure of 20%. This figure is evaluated using the recorded implementation of nominated flexibilities from the records of the DSO. Out of every 100 nominated flexibilities 30% are implemented and 70% just available but not implemented (quoted figures from the findings of the DSO and referenced in the above paragraphs).

As can be appreciated, Cyprus is still without a market of flexibility and thus the best estimation of benefits that can incur through the provision of available flexibilities are the rewards indicated in the paragraphs above by the local DSO of Cyprus.

However, the University of Cyprus is operating the campus as an energy community aiming to be fully transformed to green electricity usage based on local PV generation and storage usage to maximise benefits to internal users but offering services to the grid as well. For this reason in the paragraphs below the planned energy system of the university is unfolded giving evidence of anticipated benefits that can accumulate by utilising the benefits of flexibility coming through the GOFLEX adapted solutions.

5.2.3 The current system of UCY

The university through the GOFLEX project has connected all the loads of the university to a single point through a central management system (financed through own funds) capable of controlling loads through direct control through the BEMSs of four buildings. The BEMSs of 4 buildings are already connected to the central system and more are planned to be connected in the near future.

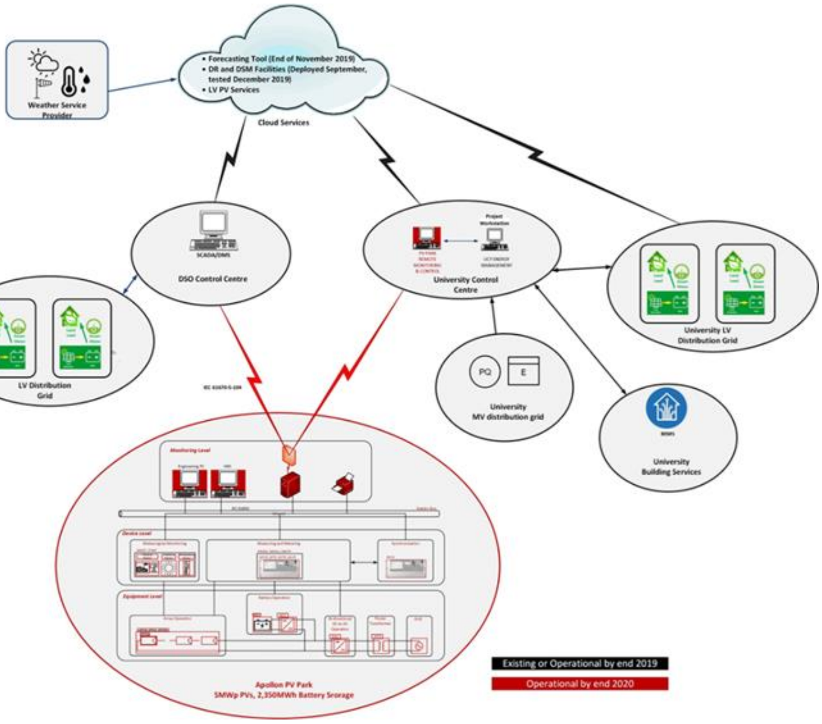


Figure 33: Schematic of the interconnected grid of UCY

Moreover, 18 multifunctional smart meters have been installed through the GOFLEX project that are giving all the required information to the central management system allowing campus planning and reporting.

This offers DR capabilities and generation of available energy flexibility to be traded with the local DSO in meeting grid services. In parallel, the DSO has achieved connectivity with the targeted prosumers equipped with smart appliances to offer DR and flexibility trading capabilities. To this effect 18 prosumers have been directly connected to the current flexibility trading platform that has been developed through GOFLEX.

The systems are in place both at the university (see the schematic of the system in Figure 1) and the individual prosumers to offer the targeted functionalities with smart meters installed offering all the flexibilities for profile response. Loads have been identified for the purpose of the project that are used to generate flexibilities for implementing real time flexibility trading as developed through the GOFLEX project. This is further facilitated by the broadband connectivity between the DSO and UCY that is already in place using dedicated fiber optic / PLC connectivity and dedicated servers providing seamless bidirectional data flow.

This functionality is depicted in the use case below:

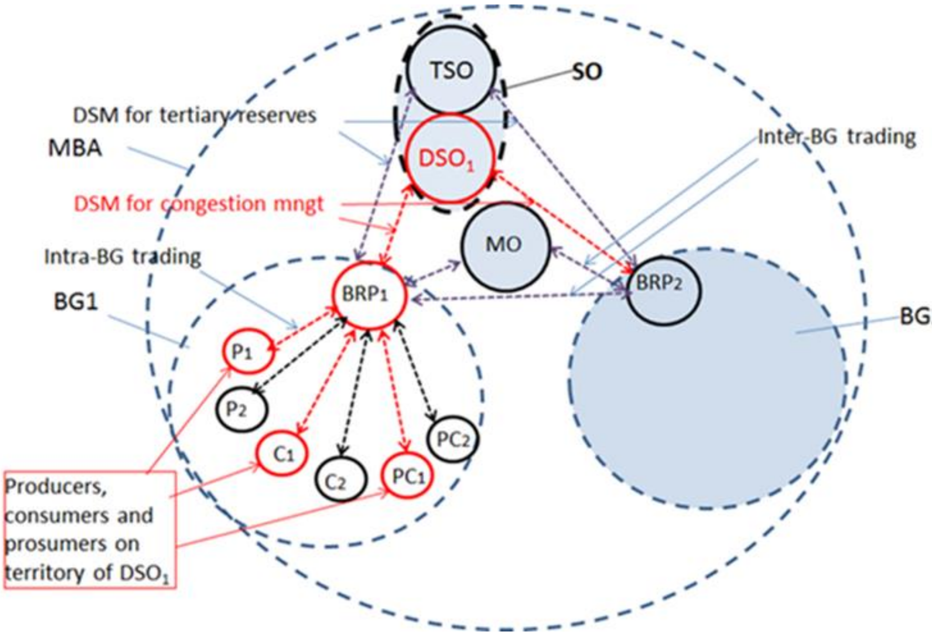


Figure 34: Schematic of the use case flexibility market at the Nicosia Demo

Within the university campus, a nanogrid has been developed offering full analysis of the interconnected system at smaller scale. This was developed during the GOFLEX project through external funds to facilitate exhaustive testing in real conditions and give valuable data for the simulation work conducted through the project.

This nanogrid has a 34.9 kWp PV production and the main electrical consumption consists of the building loads (air-conditioning units, lighting, two refrigerators, office equipment, etc.). Apart from the existing loads and systems, new equipment that has been installed includes a programmable electrical load to facilitate alternative load capabilities and emulation of residential consumption profiles, a smart EV charging station and a 10 kWhr battery storage system with a dedicated energy management system, controllable and uncontrollable load of the FOSS lab and a central software management system for data collection, analysis and reporting capabilities.

The measurements conducted during the GOFLEX project in parallel with the operation of the flexibility platform, concern the active and reactive power (imported and exported), voltage magnitude for each phase and frequency. For this reason, three new smart bidirectional meters have been installed together with other complimentary sensors and accessories to ensure adequate observability. Figure 3 provides the details about the constituent parts of the nanogrid. It must be noted that all simulations have been done with this layout.

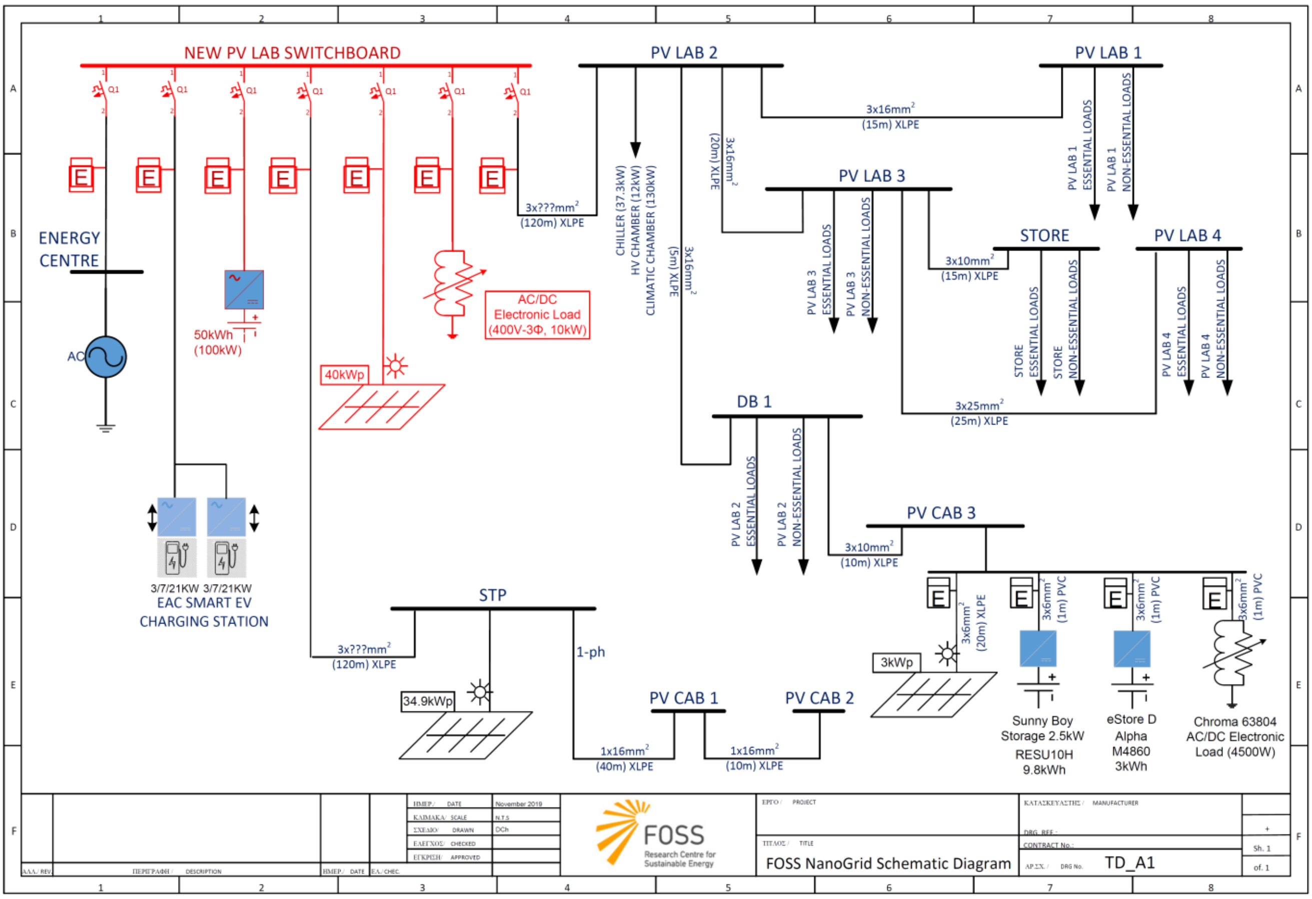


Figure 35: Single Line Diagram of FOSS microgrid

The main components of the microgrid are the following:

- Three-phase symmetrical MV grid
- A central switch for the connection with the main grid (Point of Common Coupling – PCC)
- Active/Reactive power meters
- 50kWh central battery storage system
- Battery emulating the EV charging station
- PV systems installed within the FOSS premises
- Buildings within FOSS:
    - PV Lab 1
    - PV Lab 2
    - PV Lab 3
    - PV Lab 4
    - DB_1
    - Store

The nanogrid, which consists of a small single-phase PV system, a battery and a controllable load.

The several loads with the respective cable connections are also shown in the single line diagram, as it is presented in Figure 3. In this Figure, there are also depicted the characteristics of the EV charging station. The nominal power of the PV system is 34.9kWp.

The nanogrid consists of the following:

- Single-phase PV system of 3kWp
- Battery Energy Storage System of 9.8kWh
- Controllable load of 4.5kW
- charging / discharging energy management system (CDEMS) provided by Robotina

The load types within the FOSS microgrid are as follows:

- 13 A/C Units for both Cooling and Heating
- 25 PCs
- 1 fridge
- 1 EV charging station
- Necessary office loads of 5 buildings (lights, sockets, etc.)

5.2.4 Software used for simulation work is DigSILENT PowerFactory

In order to evaluate the nanogrid from technical point of view, the DigSILENT PowerFactory software was used. Regarding the economic evaluation of the microgrid, a Cost-Benefit Analysis (CBA) is carried out, considering the current regulatory system in Cyprus.

The DigSILENT PowerFactory is a leading power system analysis software application for use in analysing generation, transmission, distribution and industrial systems. It covers the full range of functionality from standard features to highly sophisticated and advanced applications including wind power, distributed generation, real-time simulation and performance monitoring for system testing and supervision. It combines reliable and flexible system modelling capabilities with state-of-the-art algorithms and a unique database concept. Also, with its flexibility for scripting and interfacing, it is suited to highly automated and integrated solutions in business applications.

Complex studies for the integration of renewable generation into electrical networks are one of the key issues of nowadays network planning and analysis. PowerFactory combines extensive modelling capabilities with advanced solution algorithms, thereby providing the analyst with tools to undertake the full range of studies required for grid connection and grid impact analysis of photovoltaic (PV) plants and all other kind of power park modules using renewable energies:

- Steady-state load flow calculations considering voltage-dependent reactive power capability limits, power park controllers with setpoint characteristics, etc.
- Short-circuit calculation acc. to IEC 60909 (incl. 2016 edition)
- Power quality assessment according to IEC 61400-21, plus capability to consider frequency-dependent Norton equivalents

- Balanced and unbalanced stability and EMT analysis
- Models for all established generator/converter types, controlled shunts and STATCOMs
- Dynamic models acc. to IEC 61400-27-1 and WECC
- Model frequency response analysis (Bode and Nyquist Diagrams)
- Interface for real-time measurement data from DIgSILENT monitoring system PFM for online grid code compliance supervision or model validation

The circuit designed in DigSILENT PowerFactory software has been tested for the steady-state, transient and dynamic operation as per the above models.

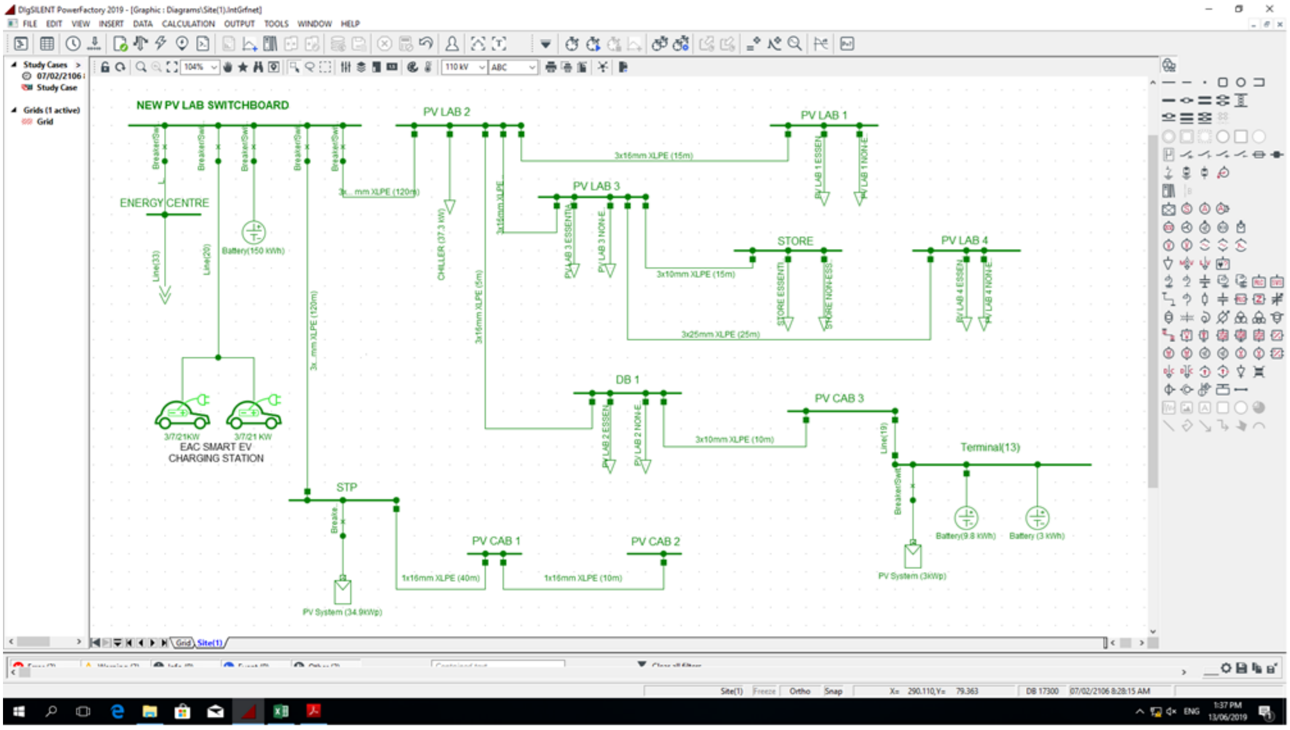


Figure 36: Nanogrid single line diagram

5.2.5 Financial evaluation of the UCY Energy Community

The objective of the economic analysis is related to the current operation of the nanogrid and the future operation of the University of Cyprus campus microgrid. The viability and the feasibility of a microgrid with PV intermittent generation and Battery Energy Storage System (BESS) is studied, while the billing scheme followed in this analysis is the net-billing scheme, which is the actual tariff agreement with the local supplier.

A cost-benefit analysis of the UCY campus microgrid is analysed in this section while the present data acquisition from the nanogrid is used in order to enhance the reliability of the followed approach and contribute to the correct sizing of the equipment.

5.2.5.1 Definition of the University of Cyprus campus microgrid

Energy management of the University of Cyprus campus

Currently, the measured peak load of the campus is 2.4 MW, while the locally installed photovoltaic (PV) systems at the rooftop of the buildings have a nominal power of 394.8 kWp. Additionally, each of the campus main buildings is equipped with a different Building Energy Management System (BEMS – see figure 5 below of the mimic diagram of a selected BEMS for details) that automatically monitors the electrical load demand and controls a range of building services. Currently, the produced energy is totally consumed internally by the university using the self-consumption tariff of the local supplier. As indicated above, in the upcoming years, the UCY plans to install a new solar PV installation of 10 MWp together 7.5MWh of battery storage. The optimum operation of the BESSs together with a detailed investigation of flexible loads at the university, will enhance the self-consumption and enable the provision of ancillary services to the grid.

The university campus is currently being extended, so the investment project and the purchase of the PV and battery equipment will be implemented in the following two phases:

- firstly, the partial integration of the large PV installation with an appropriate size of BESS to meet the current energy needs of the campus,
- secondly, an additional PV installation with BESS to cover the needs of all the newly constructed buildings within the UCY campus microgrid.

According to the study, the installation will be implemented in two phases:

- First phase: 5MWp of PV will be installed combined with 2.35MWh battery energy storage system,
- Second phase: an additional 5MWp PV system will be installed combined with 5.15MWh battery energy storage system.

The cost and benefit analysis covered in this report uses a complete one-year data of the university energy system as these were collected by the energy monitoring system provided by GOFLEX (own funds).

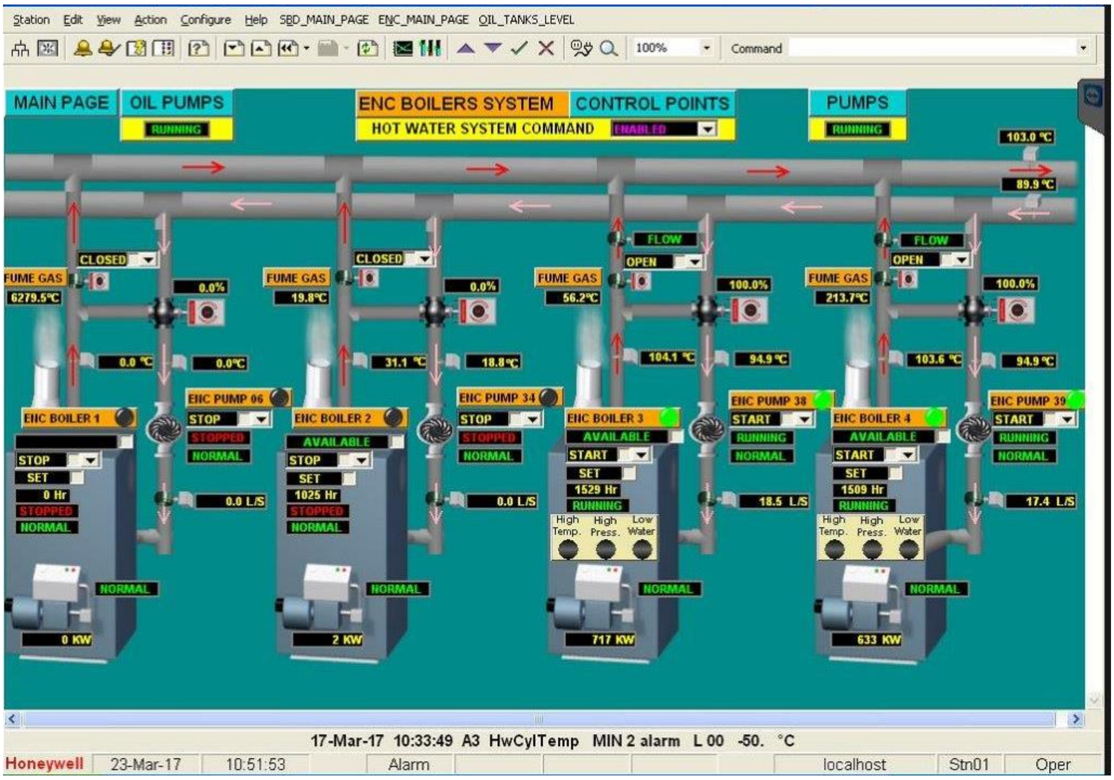


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Figure 37: Control of the loads through the BEMS

Electrical Consumption

In order to perform the Cost-Benefit Analysis (CBA), the electrical consumption of the UCY campus will be initially presented. For this reason, electricity consumption and demand profiles of the university have been extracted based on measurements provided by the energy monitoring system with a 15-minute interval, for the year 2019. These were cross checked with the data of the two grid incoming feeders which were provided by the DSO. The UCY is an educational institution with variations in electricity demand across different days of the week and within the seasons, hence its load profile will be analyzed using on the following classification:

- Working days, from Monday to Friday, and
- Non-working days, such as public holidays, Saturdays, Sundays and non-school days.

The analysis considers these two basic classifications in order to distinguish all the possibilities of the consumption profiles. The current and future average daily electricity consumption of the University campus under these classifications can be seen in Figure 38, where a consumption peak in September was expected. The reason behind the peak is the type of electrical loads, which mainly consist of electrical cooling, due to high temperatures in Cyprus and the occupancy of the campus in this period. The high consumption period is within the working summer months (June-July) and September.

Furthermore, the type of heating loads should also be considered. Currently, fuel oil is used, while in the new buildings electrical heat pumps are planned to be installed. This is an important factor for the future design and sizing of the microgrid.

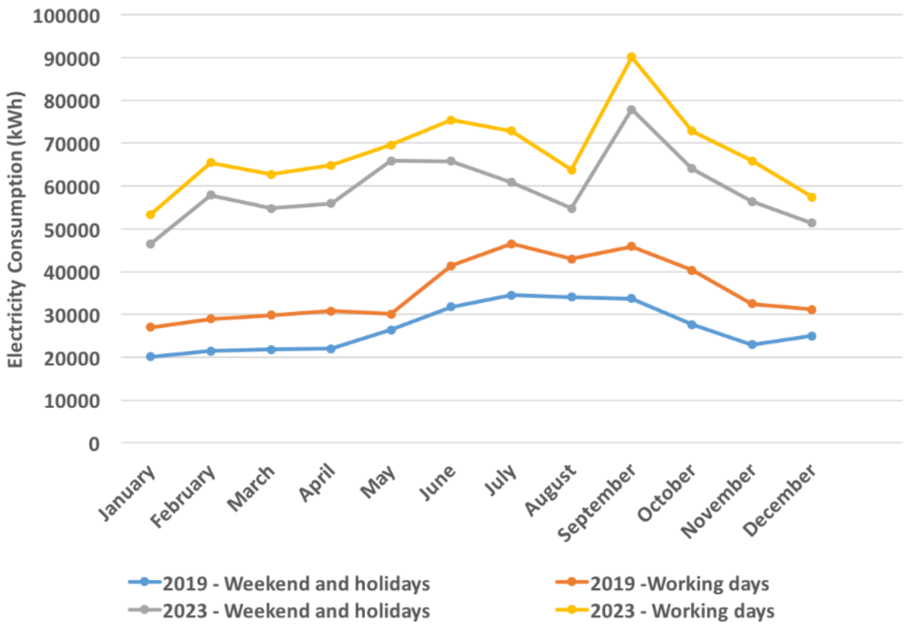

Figure 38: Current and estimated future average daily electricity consumption of UCY campus

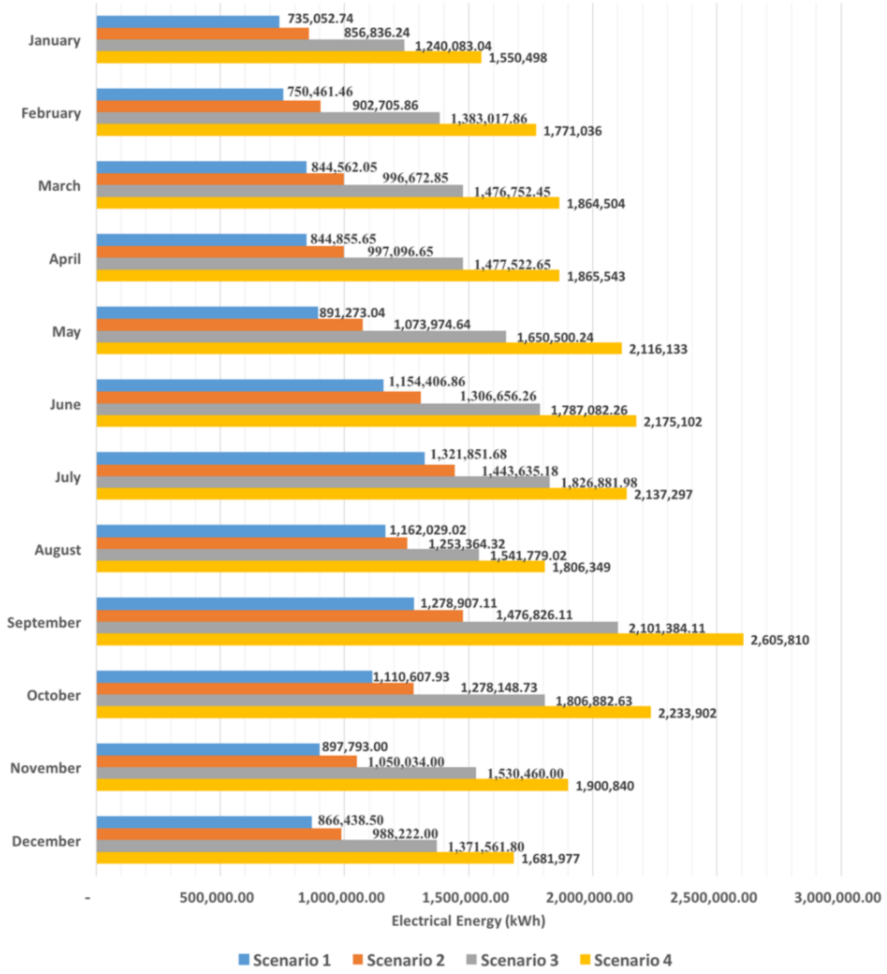

Figure 39: Current and future load profile of UCY campus

PV energy production

In this report, actual measurements from the existing PV installation have been used, in order to extrapolate the expected annual energy yield of a 10 MWp PV system. Furthermore, the unity power factor of the campus load and an annual degradation rate of 1% of the PV systems have been considered in the presented calculations, in order to estimate correctly the energy yield of the system for a period of 20 years. The generated energy of the 10 MWp system has been adapted to hourly generation profiles and compared with the hourly consumption profiles of the campus for the whole year, in order to identify the energy excesses and deficits of the PV system within a specific period of time. Figure 40 shows the hourly PV generation profile of the 10 MWp PV system on a typical day of each month.

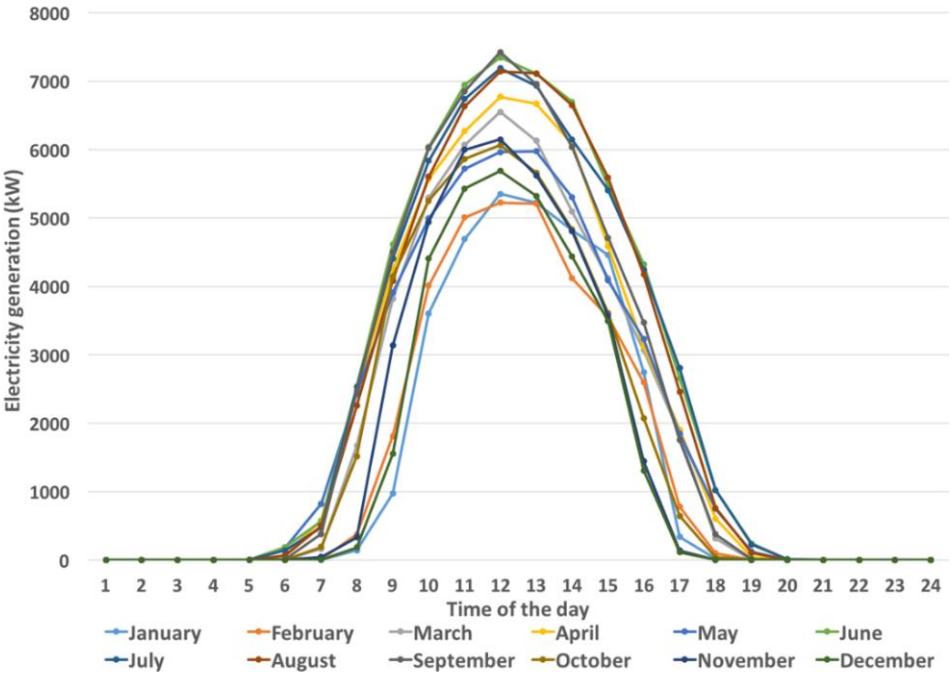

Figure 40: Hourly generation curve from the projected 10MWp PV installation

The planning period in the case study is 20 years and the technical considerations of the microgrid design aim is to minimize the energy cost of UCY by utilizing the generated energy from the installed RES and the services gained through the operation of the planned BESS system.

Net-Billing tariff

The energy bill payment of the university is estimated using predefined Time of Use (ToU) tariffs. There are several consumption tariffs and eight different price periods (P1-P8), that are based on the definition of different electrical seasons and type of days. Table 20 shows the ToU tariffs, the hourly energy price and the fixed power fees, including taxes, that are paid by the University.

Table 20: ToU tarriffs applied to the UCY electricity bill

Months	**Days**	**Hours**	**Price Periods**	**Energy Price (kWh^{-1})**	**Fixed Fee ()**
October to May	Monday to Friday	16:00 – 23:00	P1	0.1783	0.086 per day
		23:00 – 16:00	P2	0.1644	
	Weekends	16:00 – 23:00	P3	0.1738	
		23:00 – 16:00	P4	0.1605	
June to September	Monday to Friday	09:00 – 23:00	P5	0.2229	
		23:00 – 09:00	P6	0.1745	
	Weekends	09:00 – 23:00	P7	0.1771	
		23:00 – 09:00	P8	0.1719	

The pricing scheme of this report takes into account the addition of a net-billing service on top of the ToU pricing scheme. Thus, all the PV electricity injected into the grid is remunerated at the avoided generation cost, but energy not injected in the grid and it is self-consumed the following costs should be paid:

Table 21: Net metering tariff structure

Public service obligation in cents / kWh (self or purchased)	0.083
Green tax in cents / kWh (self or purchased)	1.00
VAT applied on all traded energy (exported or imported)	19.00%
Net billing charge for all energy self-consumed in cents per kWh	1.63
RES cost – Avoidance cost in cents/kWh	12.11

Evaluating costs and benefits for the UCY energy community

An initial optimization process is pursued to facilitate the investment decision. The optimization method decides the optimum combination of PV and BESS systems that will minimize the costs of the electricity bill for the UCY campus microgrid. The BESS is generally charged during periods that PV generation exceeds the campus loads, in order to minimize grid purchases during peak hours. In order to find the most optimal investment option, different combinations are considered. The annual generation (historical data available in the systems of UCY from actual PV systems currently in operation within the campus are used for realistic evaluation of annual PV generation within the campus) and consumption profiles (see the table below for details) are used in conjunction with the net billing tariff presented in the paragraph above for evaluating the net benefit for each selected combination of PV and BESS systems. All the charges and levies are included as part of the cost implications of the prevailing net billing tariff and storage is utilized to avoid peak prices to the maximum degree possible. As is seen in the paragraph above the tariff includes time-based prices and this adds more complexity to the calculations but with added benefits to the investor.

Table 22: Monthly energy analysis of UCY campus

Month	Consumption (kWh)
January	1,550,498
February	1,771,036
March	1,864,504
April	1,865,543
May	2,116,133
June	2,175,102
July	2,137,297
August	1,806,349
September	2,605,810
October	2,233,902
November	1,900,840
December	1,681,977
Annual	***23,708,992***

The economic profitability analysis considers the first phase investment objectives of UCY. Different configurations have been studied, namely:

- No PV, no Storage
- PV, no storage
    - 5 MWp PV
    - 6 MWp PV
    - 7 MWp PV
    - 8 MWP PV
- PV & storage
    - 5 MWp PV, 2.35 MWh Storage
    - 6 MWp PV, 2.35 MWh Storage
    - 7 MWp PV, 2.35 MWh Storage
    - 8 MWP PV, 2.35 MWh Storage

The results of the studied configurations for the initial phase of investment can be seen in the Table below:

Table 23: Monetary saving of assessed microgrid configurations

Description	Annual energy cost in €	PV in kWp	Storage in kWh	Savings in mil €	capital cost in mil €	Generation in kWh
Without PV and S	2,413,969	0	0	0.000	0.000	0
With PV and without S	1,213,483	5,000	0	1.200	5.000	8,100,000
With PV and without S	1,008,058	6,000	0	1.406	6.000	9,720,000
With PV and without S	807,759	7,000	0	1.606	7.000	11,340,000
With PV and without S	609,486	8,000	0	1.804	8.000	12,960,000
With PV and S	1,398,670	4,000	2,350	1.015	5.410	6,480,000
With PV and S	1,286,764	4,500	2,350	1.127	5.910	7,290,000
With PV and S	1,179,485	5,000	2,350	1.234	6.410	8,100,000
With PV and S (licensed sizes)	1,075,717	5,500	2,350	1.338	6.910	8,910,000
With PV and S	974,060	6,000	2,350	1.440	7.410	9,720,000
With PV and S	773,761	7,000	2,350	1.640	8.410	11,340,000
With PV and S	674,425	7,500	2,350	1.740	8.910	12,150,000
With PV and S (Generated energy equivalent to load)	575,488	8,000	2,350	1.838	9.410	12,960,000

From the table of results, it can be seen that the benefits of the installation of the PV system outweigh its investment cost in all scenarios, resulting in a positive Net Present Value (NPV). The real Internal Rate of Return (IRR) of the studied configurations ranges from 6.7% to 13.42%. The savings to the electricity bill due to the operation of the microgrid is the main factor that is considered for the profitability of the investment, in a pure economical point of view. By taking into consideration the IRR and NPV of the investment, the obtained results point to the direction of the installation of **a PV installation of 8 MWp and a battery capacity of 2.35 MWh**. A payback period of less than 7 years is evaluated with the current electricity prices giving a strong positive message for the opted solution and the adapted microgrid architecture.

It should be noted that, in this analysis, the BESS has only been considered for supplying PV generated energy to the university microgrid. Other uses of battery, such as tariff arbitraging, ancillary services and power balancing services that would increase the BESS's cost-effectiveness are not considered. These ancillary services will be profitable for the UCY campus microgrid, when the electricity market will move into a liberalized form.

Benefits for the DSO

Energy demand of the system is expected to be increasing year by year calling for more copper to meet growth. The increasing load demand leads to increased grid congestion or increased voltage drop, while the opposite effect of voltage increase may happen in case of injecting a high PV production directly into the grid. If an operational limit (such as thermal limit of the line) is reached, new investments on network components are needed to mitigate this issue. The presence of distributed generation and energy storage within the microgrid can reduce the maximum load demand, thereby extending the capacity use of grid components. This allows a deferral of grid investments to the future, with associated benefits to the DSO. Since maximum demand occurs only a few hours per year, the microgrid operation can provide a reliable way to avoid Transmission and Distribution grid reinforcements by relieving peaks in demand, compensating for large feed-in from renewables and generally helping to balance the system and stabilize the grid. An estimation of the financial gains can be made, based on the assumption that the estimated grid investments of the DSO are avoided.

A first estimation of the financial gains is modelled by the difference in maximum peak demand between the Basic Load Curve, and the Resulting Load Curve after the operation of the microgrid. The equation used to estimate the ratio of investment savings is the following:

$$PD_{ratio} = \frac{PD_{RLC}}{PD_{BLC}}$$

where PD_{BLC} is the peak demand of the base scenario curve, PD_{RLC} is the peak demand of the load curve after the microgrid operation and PD_{ratio} is the ratio between the maximum values of the two load curves.

As it is shown in Table 24, the microgrid operation allows internal DG sources and BESS to reduce the peak demand of the campus at the PCC. A peak demand reduction of at least 3.08% is achieved in year 2021 and a peak demand reduction of 6.45% is achieved in year 2025. The load curve is reshaped, and peak demand is maintained at the same level for the whole investment period. Taking into account that the average annual load growth in Cyprus averages to 1.5%, this reduction in peak grid loading allows distribution network investment and upgrade costs to be deferred for the 20-year planning horizon of the investment.

Table 24: Peak demand before and after the microgrid operation in years 2021 and 2025

Month	2021			2025		
	PD_{BLC} (kW)	PD_{RLC} (kW)	PD_{Rati} (%)	PD_{BLC} (kW)	PD_{RLC} (kW)	PD_{Ratio} (%)
January	424.49	411.33	96.90	891.3	822.7	92.30
February	485.33	470.30	96.90	1160.0	1044.2	90.02
March	465.49	443.85	95.35	1046.0	942.2	90.08
April	483.28	439.65	90.97	1127.6	928.1	82.30
May	645.46	563.97	87.35	1316.3	1130.9	85.92
June	777.42	624.58	80.34	1421.8	1044.3	73.45
July	792.83	690.30	87.07	1291.7	1158.7	89.70
August	684.89	532.45	77.74	1036.6	757.9	73.11
September	736.11	604.83	82.17	1573.8	1319.7	83.86
October	650.71	600.98	92.36	1336.7	1237.0	92.54
November	512.31	496.51	96.92	1101.9	1027.0	93.20
December	462.11	447.83	96.91	919.7	860.34	93.55

In order to estimate the financial benefits of the differed grid investments, economic data of the DSO of Cyprus regarding the Transmission and Distribution Network development, upgrade and maintenance costs from 2012 to 2016 were examined. These costs range from 16.86 to 50.26 million per year, resulting to average annual costs of 31.34 million. To obtain typical figures, the estimated upgrade cost of the distribution grid of Cyprus was taken into consideration and the average marginal grid investments per total system capacity were used as an approximation for the cost per megawatt of investments. Thus, it was estimated that the microgrid operation results to annual grid deferral savings of 21,200 per year.

The postponed future grid investments in 20 years are then valued and discounted over the years in order to obtain an NPV. The NPV of all the postponed investments is calculated using the total cost of the planned grid investments for the scheduled year i and the interest rate as follows:

$$NPV_{inv} = \sum_{i=1}^{20} \frac{C_i}{(1+r)^i}$$

where NPV_{inv} is the NPV of all the postponed investments, C_i is the value of the postponed investment of the i^{th} year and r is the discount rate that refers to the interest rate used in cash flow analysis to determine the present value of future cash flows.

Furthermore, reduced grid losses, which can be represented by the difference between the grid losses before and after the microgrid operation, have a potential to represent savings in monetary terms for the DSO. Total savings from avoided PV generation grid losses take into account the system availability and grid connection power losses (ηPPC) that are saved due to increased self-consumption of the PV generated energy. These losses, based on grid data of the past 5 years, range on average at 4.42% in the island of Cyprus. The annual financial benefit of the avoided distribution losses is calculated as follows:

$$\pi_{losses} = \sum_{d=1}^{365} [\eta_{PPC} * PV'_{cons_i} * P_{PV}]$$

where P_{PV} is the wholesale electricity price that is offered by the utility for the energy that is sold to the grid and PV'_{cons_i} is the amount of PV generation that is directly consumed or stored by the microgrid in a single day.

Reducing the losses through the microgrid operation, provides the DSO with an economical incentive to support microgrid integration if the benefits are significant. The function that expresses the NPV of the DSO profit is formulated for the 20-year period year using the following equation:

$$NPV_{DSO} = NPV_{inv} + \sum_{i=1}^{Y} \frac{\pi_{losses} + PV_{excess}}{(1+r)^i}$$

where PV_{excess} is the annual amount of PV generated energy that is fed back to the grid without compensation.

The operation of the microgrid results in monetary benefits of 1,002,282.4 for the DSO. The gains obtained under this scenario are derived from the reduction of distribution grid losses and the deferral of grid investments. It is assumed in this study that the DG and BESS investment can be a direct substitute to the “wires and poles” assets; thus, the same discount rate has been applied to both cases. Nevertheless, it is apparent from the obtained results that the microgrid operation would be both beneficial and profitable for the DSO.

5.2.6 Conclusions

In this report, the economic evaluation of the UCY Energy Community in Cyprus is presented in relation to the GOFLEX project. Regarding the technical analysis, the FOSS microgrid case is examined, where representative simulation tests present the steady-state, transient and dynamic operation of the microgrid. The results of the UCY nanogrid and the measured data from the installed equipment will be used for designing future investments of the UCY campus.

The optimal sizing of the PV - battery storage combination has been determined based on a cost and benefit analysis. The quantitative results of the studied scenarios in all of the cases that have been proposed in the sensitivity analysis, show that the installation of the BESS would increase the benefit for the microgrid and that the obtained benefits from the operation of the microgrid outweigh its investment cost giving a payback period of less than 7 years with many other added advantages.

Moreover, this report has examined the potential for the microgrid to act as an alternative DSO option by providing an assessment of the added benefits to the interconnected grid. Obtained results show that the microgrid operation can defer the upgrade of transmission and distribution grids and is able to lower their capacity demand. Furthermore, the added benefit brought by the reduction of grid losses provides another direct benefit for the environment and the DSO as well.

Through the GOFLEX project the remuneration of traded flexibilities has been developed offering an operational platform that has revealed its strengths. This will add additional benefits to Energy Communities by effectively using their available flexibilities benefiting the wider needs of the interconnected grid.

It is to be noted that the above are based on figures of the university campus energy community and not on the nanogrid. Output figures, however, are comparable and all benefits noted can very well fit all sizes giving a strong evidence of the attainable benefits of using microgrid architectural solutions for satisfying commercial, industrial and community energy needs.

6 Conclusions

We, Cyprus partners, consider GOFLEX as a breakthrough in the fields of flexibility management and trading. Though optimistic in its endeavours, its end-to-end platform has managed to provide high TRL solutions for multiple stakeholders, in our case the DSO as system operator, aggregator, and market operator and UCY as microgrid operator.

Cyprus demo site followed gradual implementation, both of the outskirt user systems as well as communication and configuration of the central platform solutions instances. We verified flexibility readiness of the users through ad-hoc tests and then performed regular testing.

Despite multiple challenges faced, mostly on the user side, the Cyprus demo site managed to effectively test and prove the use cases under interest, fulfilling the objectives of the call, and verifying performance through platform-trackable and other derived metrics. These results have been exploited in cost-benefit analyses for the business cases of the Cypriot partners yielding profitable flexibility trading business scenarios. Lessons learnt will accompany the Cypriot partners in their further endeavors in exploiting flexibility in their business scenarios.

7 References

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