Demonstration Tools for Trading Flexibility in Distribution Grids in Cyprus - The Cases of a Microgrid and Dispersed Prosumers

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ABSTRACT

In order to achieve the ambitious targets of the European Union (EU) regarding the integration of Renewable Energy Sources (RES) without the need for significant grid reinforcements, new integrated solutions should enable demand-response schemes and combine the operation of RES with smart grid technologies and energy storage systems. Towards this direction, GOFLEX, being a Horizon 2020 European Project, aims at demonstrating flexibility-trading solutions for cost effective use of demand response schemes in distribution grids. The field tests in Cyprus investigate the cases of the microgrid and the single prosumer. For each case, the role of the Balancing Responsible Party (BRP)/Aggregator is assigned, as an intermediate level for trading flexibility between the microgrid/prosumers and the Distribution System Operator (DSO).

Regarding the microgrid case, the campus of the University of Cyprus (UCY) will be examined. This currently consists of several different Building Energy Management Systems (BEMS) for controlling the heating and cooling and 350 kWp Photovoltaics (PV). A 10 MWp PV system is also planned to be installed (first phase 5 MWp to be operational within the GOFLEX project) combined with a large energy storage system and a public EV charging station, thus transforming the university campus into an enabled microgrid capable of minimizing the energy cost to the university through effective use of the self-consumption scheme offered by the local Supplier. Therefore, new challenges for offering flexibility to the distribution grid emerge in the form of creating profitable business models for both the UCY and DSO. Concerning the dispersed prosumers within Cyprus, Home Energy Management Systems (HEMS) will be installed at the premises of 26 prosumers with 3 kWp rooftop PV for offering flexibility to the DSO and adopting more grid-friendly energy practices. Another 10 prosumers will test the flexibility from one single load, in order to compare the results with the more complicated HEMS solution. Finally, for both cases, a new tool will be utilised by the DSO to analyse the distribution grid and identify its flexibility needs.

Therefore, this paper is focused on investigating the flexibility offered by single prosumers and microgrids in islanded distribution grids in order to satisfy the DSO requirements. Through the installed equipment and the gathered results, new business models will emerge, providing the market environment for the commercialization of the proposed solutions throughout the EU.

1 INTRODUCTION

In order to implement the vision for vast expansion of RES, EU set the target of 20% for RES production, as described in the Directive on Renewable Energy Sources [1]. However, with the current structure of the distribution networks, certain issues have been raised preventing the fulfillment of the set targets, such as grid congestion, voltage increase, frequency deviations, high-order harmonic pollution, protection malfunctions, etc. [2, 3]. A serious factor for the aforementioned issues is based on the intermittent and the highly volatile nature of the RES. Therefore, technically and economically viable solutions have been proposed in the literature.

Initially, the upgrade of the distribution grid, especially in areas of concentrated RES have been implemented by the Distribution System Operators (DSOs). However, the gird reinforcement is not economic, efficient and, in some cases, even not technically possible [4, 5]. Other possible solutions propose the connection of external devices, such as bulk storage systems, in certain nodes within the distribution grids [6-8]. Nevertheless, this solution will be more prominent as prices go down , while it can be implemented even today under certain circumstances, e.g. space limitations.

On the other side, a prominent solution is the utilization of existing resources in a more efficient way, serving the requirements of the DSOs. Therefore, the utilization of local flexibility appears as a more appealing alternative, especially considering the upcoming ability of consumers to contribute flexibility based on the advances of smart meters and distributed energy storage technology [9-11]. Another important factor contributing to this direction is the transformation of the operational principles of the national electricity markets towards the fully liberalized model. New actors, such as Demand Response (DR) Aggregators have emerged, gained serious attention and popularity [12-15].

Many EU funded projects deal with the smart grids, proposing promising solutions in specific technological areas, such as DR schemes, energy storage systems, energy management systems, electrification of transport, distribution grid monitoring and management, and, energy data management infrastructure. However, no replicable and scalable solution has been demonstrated so far, which will identify the real integrated demand and supply opportunities of the prosumers and offer services to the upstream distribution grid by trading the flexibility in the organized electricity market. GOFLEX EU project fills this gap by demonstrating integrated, scalable and replicable solutions, which combine existing and validated tools.

Cyprus participates in GOFLEX with two demonstration cases, the UCY campus microgrid and dispersed prosumers within Cyprus. Through this participation, the identification of the grid issues and the capability of providing flexibility as prominent solution will be researched, while new business models for adopting the results will be proposed.

This paper presents analytically the flexibility concept behind GOFLEX, concentrating on the Cyprus demonstration cases. Section 2 analyses the general and Cyprus architecture, while Section 3 presents the business models and the new opportunities for trading flexibility. Finally, Section 4 summarizes the results of this paper.

2 GOFLEX SOLUTIONS IN CYPRUS DEMONSTRATION SITES

2.1 Conceptual Architecture of GOFLEX

The conceptual architecture of GOFLEX is summarized in Figure 1. At the lower level, the prosumer infrastructure is described, which consists of households, microgrids, Electrical Vehicle (EV) charging stations and thermal storage facilities. Regarding the Cyprus demonstration cases, the UCY campus microgrid, dispersed households and EV charging stations will be tested. The target is through the successful implementation of energy management systems at the prosumers to provide flexibility offers by combining the energy production from RES (if any) with the energy consumption and storage capability. In order to incentivise the prosumers to participate to this scheme, the dynamic pricing scheme will be adopted.

At an upper level, the flexibility offers (called FlexOffers) are gathered by an intermediate market actor, such as Aggregator, BRP or Virtual Power Plant (VPP). Similarly, the DSO systems are producing FlexOffers by monitoring the grid and identifying possible grid issues, such as grid congestion. All kind of FlexOffers are supported by cloud-based services, while weather services are utilised in order to provide more accurate FlexOffers. Finally, the Flexibility Market System will match the FlexOffers from the Aggregator/BRP/VPP with the respective DSO.

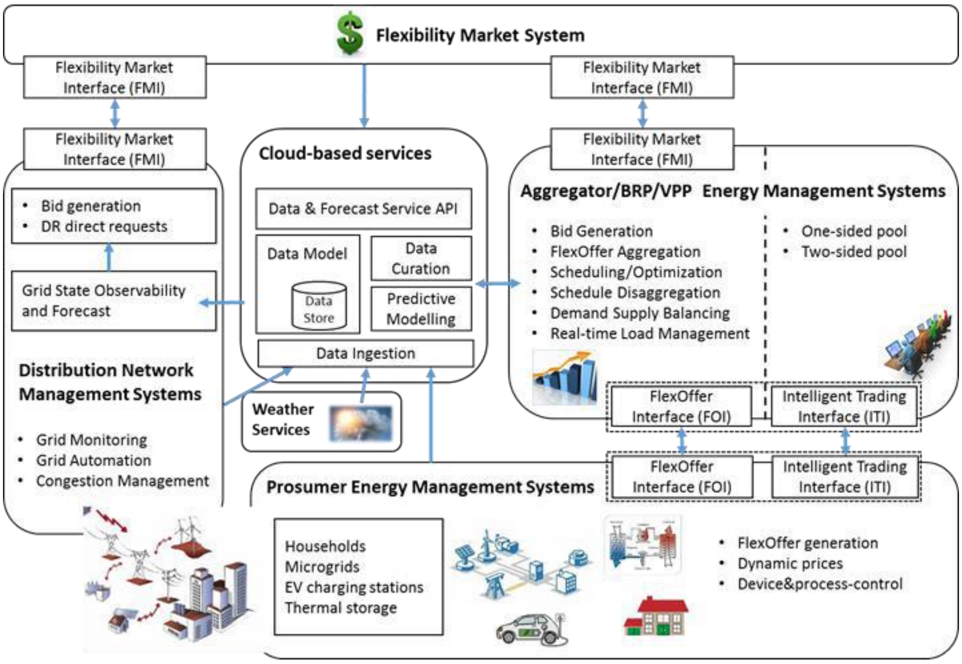

Figure 1: Conceptual Architecture of the GOFLEX proposed solution

2.2 Architecture of Cyprus demonstration cases

Following the generalized concept of GOFLEX, Figure 2 depicts the architecture of Cyprus demonstration case, which consists of the following elements:

- *Home Energy Management Systems (HEMS)*: the target of HEMS is to effectively control the household loads and provide monitoring opportunities to the prosumers. The HEMS have the ability to integrate both the energy production (by the rooftop PV), the energy storage systems, which are batteries in case of Cyprus, and the energy consumption. Furthermore, the HEMS will be able to communicate with the Smart Meters (SM) at the prosumer premises. In GOFLEX, the HEMS will be provided by Robotina.
- *Charging-Discharging Energy Management Systems (CDEMS)*: The CDEMS will be located at the EV charging station of UCY, in order to test the flexibility opportunities of the EVs.
- *Building Energy Management Systems (BEMS)* and *complex BEMS*: Each of the 8 existing buildings of UCY is controlled with a separate BEMS. Several sensors (such as temperature sensors) are placed within each building and cooperate with the BEMS. However, since different types from different manufacturers (such as Siemens, Honeywell, Satchwell and Johnsons Controls) are operated, a complex BEMS that integrates the different operational principles and protocols is required in order to provide a central control capability for the UCY microgrid campus.

- *PV Energy Management System (PV EMS)*: Currently, the PV EMS concerns the existing spread PV installations, which is 350kWp. However, within the next years another 10MWp PV will be installed, which will be part of the total UCY microgrid production.
- *Storage Energy Management System (Storage EMS)*: The Storage EMS will control the battery storage system of the microgrid. When the large PV will be installed, new energy storage systems both central and distributed will be placed within the UCY microgrid, contributing to the total flexibility opportunities.
- *FlexOffer Agent (FOA)*: The FOA consists of two parts, the software and hardware and it is responsible for collecting the flexibility offers in order to be traded. Each prosumer will be equipped with FOA with appropriate communication interfaces, relays and meters.
- *Automatic Trading Platform (ATP)*: The ATP will be able to support two types of trading mechanisms: direct trading and delegated trading. These tools will be provided by INEA.
- *Distribution Observability Management System (DOMS)*: This tool concerns the DSO and it is a data analytics software, which is used in order to predict the grid state and identify grid congestion issue. The target through this tool is to manage the grid in a more efficient way. The measurement for DOMS will be gathered on grid connection points or transformer substations, depending on the availability of the metering infrastructure.
- *Distribution Management System (DMS)*: The DMS will be the central server, being installed at DSO premises.
- *Service Platform*: The target of the Service Platform is the gathering of the grid point readings and smart meter readings on the DMS Server. The Data will be anonymized and transmitted to Service Platform using standard protocols (e.g. MQTT). Interval of transmission will be based on availability of metering data on DMS system.

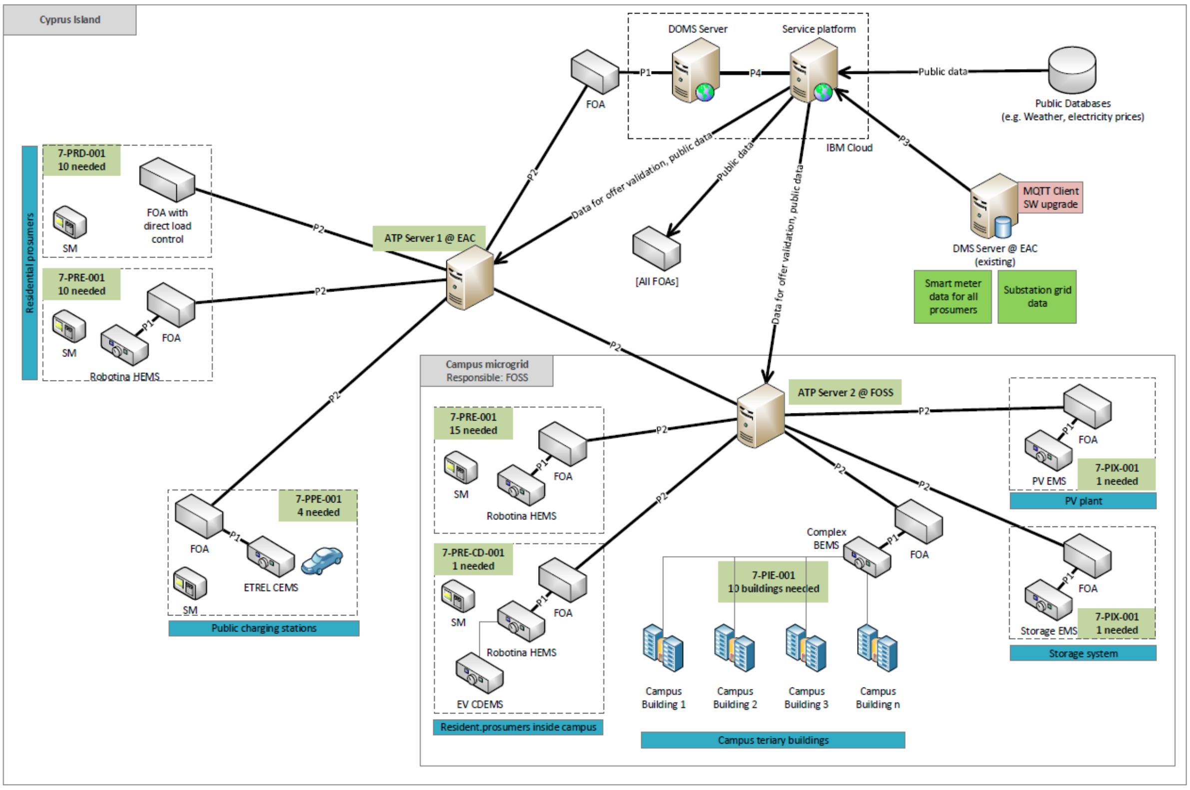

Figure 2: Cyprus demonstration case architecture

3 BUSINESS MODELS

3.1 GOFLEX Methodology Approach

In GOFLEX, new business models will be demonstrated and verified through detailed field tests. Three tools will be used in order to develop the business models:

- Visualised Unified Modelling Language (UML) Diagrams [16]: this tool intents to identify the interactions between actors for each business model. It is a common methodology for identifying, clarifying and organizing the system requirements. A use case diagram is a graphic description of the interactions among the elements of a system, consisting of four components:
  - *(i)* the boundary, which defines the system of interest in relation to the world around it,
  - *(ii)* the actors, usually individuals involved with the system defined according to their roles,
  - *(iii)* the uses cases, which relate to the specific roles played by the actors within and around the system and
  - *(iv)* the relationships between and among the actors and the use cases.
- Business model Canvas [17]: this tool analyses the details of each business model by describing in deep the individual components, as it appears in Figure 3.

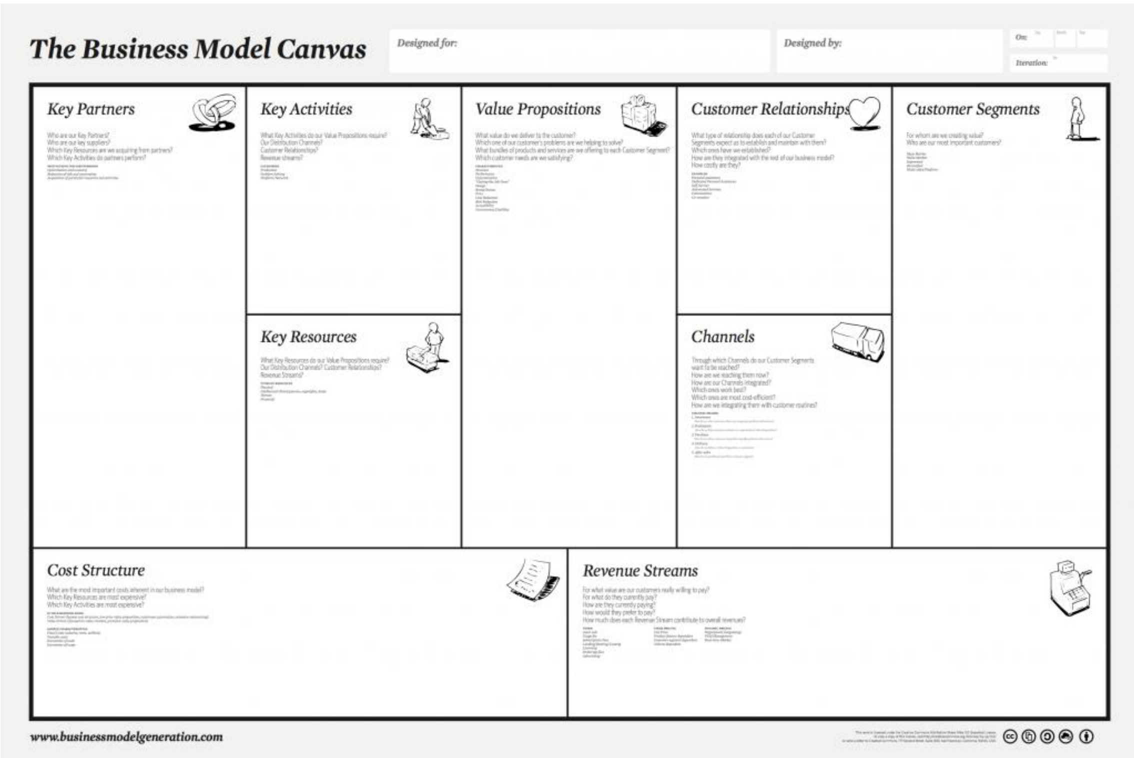

Figure 3: The business case Canvas

- Cost-Benefit Analysis: in order to implement a business model, a positive case should arise. The financial figures will be assumed based on existing predictions and getting real data from the demonstration site. Two types of costs are considered:
  - *(i)* Fixed costs: these costs remain the same despite the volume of goods or services produced. For example, this cost category can apply to the costs in order to establish a

market platform for flexibility. The development costs are independent of the number of market actors using this platform.

(ii) Variable costs: these costs vary in proportion to the volume of goods or services produced. For example, this cost category can apply to costs directly involved with the provided access to markets for prosumers. Each prosumer needs equipment and software.

The identified revenue streams of the business models are as follows:

(i) Asset sale: this revenue corresponds to the physical product, i.e. the equipment, in order to support the self-consumption scheme and participate in the trading of flexibility.

(ii) Lending/Renting/Leasing: this revenue can apply from the temporary granting of the exclusive right to use a particular asset for a fixed time period in return for a certain fee. This type of revenue can be a part of the equipment, e.g. a part of a tariff model.

(iii) Usage fees: this type of revenue can be applied to the usage of the flexibility trading platform by the market actors and can be paid back by each successful transaction.

(iv) Subscription fees: a regular subscription fee (e.g. monthly, bi-monthly or yearly) can be imposed to market participants in order to get access to the trading platform.

(v) Licensing fees: this revenue corresponds to intellectual property, which allows the rightsholders to get revenues from their property without the need of manufacturing a product or a commercial service, as for example the license for using the platform as an Aggregator.

3.2 Business Models for Cyprus demonstration cases

3.2.1 University campus microgrid

The first demonstration case concerns the campus of University of Cyprus. The current distributed PV installations are in total 400kWp, and another large PV plant of 10MWp is under the authorization process. The installation will be split to two phases of 5MW PV each. In order to support the distribution grid, a battery energy storage is required by the DSO with nominal capacity equal to 1MWh. However, after conducting a techno-economical study, a larger battery bank will be installed, following the gradual installation of the PV. In order to define the nominal battery capacity, different pricing scenarios are regarded. Furthermore, the results of GOFLEX will contribute to this direction by elaborating the potential of the DR through the energy storage systems. Both the energy storage systems and the PV will be controlled by separate EMS. The target of the PV EMS is to maximize the generation from the PV installations, while the EMS of the storage will be controlling the charging/discharging cycles of the storage in order to ensure an extended lifetime for the batteries (control the State of Health – SoH of each battery) and at the same time contribute to the increase of the self-consumption of the university campus microgrid.

Regarding the consumption within the campus, the existing buildings are already equipped with different types of BEMS. Moreover, new buildings (library, school of engineering, biology and school of medicine) are also under construction. Therefore, new BEMS are going to be installed within the campus servicing the needs of the new buildings. In order to increase the efficient operation of the whole campus microgrid in the sense of centrally controlling the total consumption load, a central integration platform (called complex BEMS) is going to be installed, collecting the outputs of each BEMS and providing control signals to each individual BEMS. Furthermore, several sensors (such as temperature sensors, humidity sensors, etc.) are already installed in the existing buildings in order to ensure the desirable comfort zone.

Another storage system with a separate EMS is the EV charging station, which is installed within the university campus microgrid. The EMS will control the charging rate of the EV, in order to be able to offer flexibility offers. Furthermore, the case of discharging the EV will also be examined as a business case. Since the majority of the EV corresponding to students will stay for many hours in the parking and will be connected with the EV charger, the case of discharging part of the stored energy may lead to new flexibility offers. In this case, the EV owners will be remunerated for this discharging service.

Within the GOFLEX project, the complex BEMS, the PV EMS and the Storage EMS will be connected to the FOA, permitting the generation of the flexibility offers, as it is depicted in Figure 2. The outputs of the FOAs will be aggregated in the ATP Server. The ATP server is located and controlled at the Research Centre for Sustainable Energy (FOSS) premises. A direct data exchange from the ATP server and the Service Platform will take place, completing the activation of certain flexibility offers. In this structure, FOSS plays the role the Aggregator, since it gathers all flexibility offers from the installed FOAs and send them to the Service Platform. In order to increase the effectiveness of the flexibility offers, a forecast tool is utilized by the Aggregator (i.e. FOSS in the microgrid case), in order to be able to calculate the energy production from the PV installations and the total energy consumption of the microgrid. The forecasting tool can also be used for controlling the energy storage system more effectively. Regarding the DSO flexibility offers, as it can be seen from Figure 2, the Service Platform is also connected with the DOMS server, which is installed at the DSO premises. The DSO of Cyprus, which is called Electricity Authority of Cyprus (EAC) is also a partner in GOFLEX. Therefore, by utilizing the grid analysis through the DOMS tool, the DSO will be also able to activate the flexibility offers, when there are identified grid issues.

3.2.2 Dispersed prosumers within Cyprus

In the second case, the dispersed prosumers within Cyprus will be examined. In order to compare the capability of providing flexibility offers from individual prosumers, three different categories of prosumers will participate in GOFLEX:

- Prosumers with rooftop PV installation with HEMS
- Prosumers with rooftop PV installation, energy storage systems and HEMS
- Prosumers with controllable loads

Each prosumer is equipped with a Smart Meter (SM), which has a direct connection with the DSP. The prosumers will be able to trade the flexibility by utilising the FOA, which has a connection with the HEMS. In the case of a single controllable load, the prosumers will trade the flexibility of this load (e.g. water pump, air-conditioner, water heater, etc.). In this business case, the role of the Aggregator is emulated by the DSO, who will operate the ATP Server. Therefore, the Aggregator will act as a centralized controller and will handle the energy serviced derived from the analysed consumption patterns of the prosumers. Again, in this case, the ATP Server will communicate with the DOMS server in order to activate the flexibility offer, according to the grid analysis conducted by the DSO.

3.2.3 Flexibility services

The Table 1 presents three different flexibility services that have been identified for the two aforementioned demonstration cases. This table is filled after conducting the analysis with the three tools, as they are mentioned in 3.1. The graphical presentation in UML diagrams appear in Figure 4, while the cost-benefit analysis of each demonstration case is presented in Table 2.

Table 1 Flexibility Services

Service	*Service 1:* Microgrid offering flexibility to the DSO	*Service 2:* Prosumers offering flexibility to the DSO	*Service 3:* Grid congestion relief
Actor /Role	*Microgrid role*: send flex-offers for trading flexibility *Aggregator*: use the flexibility for reducing energy costs *DSO*: more predictable load without many peaks/less demand for reserves / lower energy cost	*Prosumers*: send flex-offers for trading flexibility *Aggregator*: use the flexibility for reducing energy costs *DSO*: more predictable load without many peaks/less demand for reserves / lower energy cost	*Prosumers/Microgrid*: send flex-offers for trading the flexibility *Aggregator*: use the flexibility to mitigate local congestions *DSO*: optimize grid management/deferral of grid investments

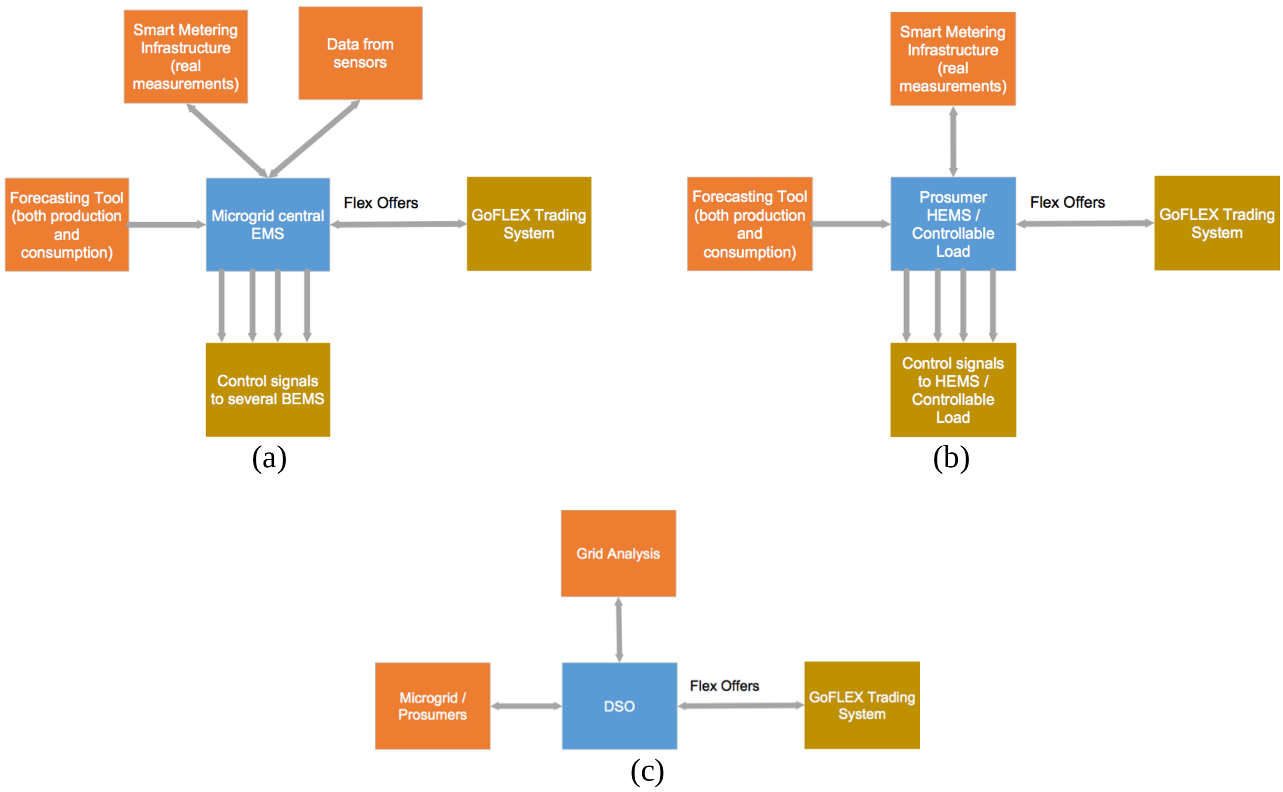

Figure 4 UML diagrams: (a) Service 1, (b) Service 2, (c) Service 3

Table 2 Cost-Benefit Analysis

University campus microgrid	
Benefits	• Financial benefits: sale of generated electricity • Energy savings and emission reduction: serve the EU's long-term goal of power sector decarbonisation and help to reduce CO_2 and SO_2 emissions • Improvement of electricity reliability and power quality: prevent sustained outages, provide ancillary services (e.g. frequency support, black-start capability, peak load saving, etc.) • Reduction of distribution losses: increase self-consumption of the microgrid, less usage of the distribution grid • Deferral of grid investments: new grid infrastructure can be postponed through the activation of the proper flexibility offers of the

	microgrid
Costs	• Capital investments: initial capital investment for purchasing and installing the equipment • Construction and operational costs: costs for the complex BEMS, installed capacity of energy storage systems and PV, control devices, monitoring systems
Dispersed Prosumers	
Benefits	• Peak-load shifting: proper planning and operation of the grid by reducing or shifting the electricity usage • Electricity saving: response to flexibility offers and maximize self-consumption. The Aggregator can also benefit by trading the aggregated flexibility • Capacity cost savings/Deferral of grid investments: new grid infrastructure can be postponed through the activation of the proper flexibility offers of the microgrid
Costs	• Investments costs: purchase of smart meters, communication costs for both sides (prosumer and DSO), purchase of HEMS, control equipment • Annual fixed costs: transactions costs, control costs, grid costs • Variable costs: costs of monitoring, maintenance costs

4 CONCLUSION

This paper analyses the trading of flexibility offers among prosumers and the DSO provided by prosumers, in order to solve grid issues, such as grid congestion. Two demonstration cases have been regarded: the microgrid of University of Cyprus campus and dispersed prosumers within Cyprus. The target of this analysis is to test the technological solutions provided within GOFLEX EU project in real environments and elaborate the different business cases that will by identified.

Regarding the university campus microgrid, the target is to increase the self-consumption and the overall efficiency by controlling in a smart way the installed PV, the energy storage systems and the total consumption of the buildings within the campus. Concerning the individual prosumers, different types of prosumers have been considered, in order to present the opportunities of flexibility under different prosumer patterns (prosumers with PV, prosumers with PV and storage, prosumers with one controllable load). Through the analysis, new business models are presented by utilizing different tools, being very promising for the adoption of this service and become a market product in a few years.

As a future work, measurements will be taken from the presented demonstration sites, where the real time operation of the flexibility trading will be tested. Therefore, the analysed business models will be validated under real conditions. The results of this work can be used as a useful tool for designing the liberalized electricity market in Cyprus.

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