OMÜ Mühendislik Bilimleri ve Teknolojisi Dergisi,
OMU Journal of Engineering Sciences and Technology

e-ISSN: 2791-8858 OMUJEST, Eylül 2024, 4(2): 49-62

Green Energy Management System for Energy Efficiency Analysis of Edge Computing Facilities

Uç Bilgi İşleme Tesislerinin Enerji Verimliliği Analizi için Yeşil Enerji Yönetim Sistemi

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Makale Bilgisi/Article Information

Makale Türü/Article Types: Araştırma Makalesi/Research Article
Geliş Tarihi/Received: 02 Ocak/January 2023
Kabul Tarihi/Accepted: 20 Eylül/September 2024
Yıl/Year: 2024 | **Cilt–Volume:** 4 | **Sayı–Issue:** 2 | **Sayfa/Pages:** 49-62

Atıf/Cite as: Şişman Korkmaz, C., Terciyanlı, A., Aboumadi, A., Aygün, İ. "Green Energy Management System for Energy Efficiency Analysis of Edge Computing Facilities" Ondokuz Mayis University Journal of Engineering Sciences and Technology 4(2), Eylül 2024: 49-62.

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GREEN ENERGY MANAGEMENT SYSTEM FOR ENERGY EFFICIENCY ANALYSIS OF EDGE COMPUTING FACILITIES

ABSTRACT

Carbon dioxide (CO2) is the main greenhouse emission emitted through human activities and is present within the atmosphere as a part of the Earth's carbon cycle. The increase in carbon emission has many negative effects such as causing climate change. Many factors play a role in the increase in this worldwide carbon emission, especially the structures that emerge with the development of technology, such as data centres, which have an important role in increasing carbon emissions. Artificial-Intelligence-Augmented Cooling System for Small Data Centres (ECO-Qube) project focuses on edge data centres since they are important because of their energy-saving potential. Several Key Performance Indicators (KPIs) are developed to evaluate the energy efficiency of the data centres and their environmental sustainability. The ECO-Qube project determines an assessment methodology for data centres following the most important standards like ASHRAE TC 9.9 2021, EN50600 Standard Series, and the EU Code of Conduct. The main KPIs used in this project are Power Usage Effectiveness (PUE), Renewable Energy Factor (REF), Energy Reuse Factor (ERF), Primary Energy Savings (PES), CO2 Savings, and performance Per Watt (PPW). These KPIs are sufficient for the real-time assessment of data centres within this project and can give a good idea of the improvements achieved. Digital technologies such as EMSs (Energy Management Systems) are part of the solution to reduce energy consumption, as they enable more efficient use of resources. From this perspective, an EMS has been designed in the scope of this project to track the energy demand, operate the energy supply in cooperation with the building/district's EMS, and calculate the project's KPIs which enables precise evaluation of data centre's current state and the effects of upgrades done to a data centre.

Keywords: Data Centres, Carbon Footprint, EMS.

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UÇ BİLGİ İŞLEME TESİSLERİNİN ENERJİ VERİMLİLİĞİ ANALİZİ İÇİN YEŞİL ENERJİ YÖNETİM SİSTEMİ

ÖZ

Karbon dioksit (CO2), insan faaliyetlerinden yayılan başlıca sera gazı emisyonudur ve Dünya'nın karbon döngüsünün bir parçası olarak atmosferde bulunur. Karbon salınımındaki artışın iklim değişikliği başta olmak üzere birçok olumsuz etkisi bulunmaktadır. Dünya çapındaki karbon emisyonunun artmasında birçok faktör rol oynsmaktsdır, özellikle teknolojinin gelişmesiyle birlikte veri merkezleri de bu faktörlerden biri haline gelmiştir. Küçük Veri Merkezleri için Yapay Zeka Artırılmış Soğutma Sistemi (ECO-Qube) projesi, enerji tasarrufu potansiyelleri nedeniyle uç veri merkezlerine odaklanmaktadır. Proje kapsamında, veri merkezlerinin enerji verimliliğini ve çevresel sürdürülebilirliğini değerlendirmek için birkaç Temel Performans Göstergesi (KPI) geliştirilmiştir. ECO-Qube projesi, ASHRAE TC 9.9 2021 ve EN50600 Standart Serisi gibi en önemli standartları izleyerek veri merkezleri için bir değerlendirme metodolojisi belirlemektedir. Bu projede kullanılan ana performans göstergeleri, Güç Kullanımı Verimliliği (PUE), Yenilenebilir Enerji Faktörü (REF), Enerji Yeniden Kullanım Faktörü (ERF), Birincil Enerji Tasarrufları (PES), CO2 Tasarrufları ve Watt Başına Performanstır (PPW). Bu göstergeler, bu proje kapsamındaki veri merkezlerinin gerçek zamanlı değerlendirmesi için yeterlidir ve elde edilen iyileştirmeler hakkında iyi bir fikir verebilir. EMS (Enerji Yönetim Sistemleri) gibi dijital teknolojiler, kaynakların daha verimli kullanılmasını sağladığından, enerji tüketimini azaltmak için çözümün bir parçasıdır. Bu bakış açısıyla, enerji talebini takip etmek, enerji arzını binanın/bölgenin EMS'si ile işbirliği içinde işletmek ve projenin KPI'larını hesaplamak için bu proje kapsamında veri merkezinin mevcut durumu ve veri merkezlerine yapılan iyileştirmelerin performansa etkilerini hassas bir şekilde değerlendirilmesini sağlayan bir EMS tasarlanmıştır.

Anahtar Kelimeler: Veri Merkezleri, Karbon Ayak İzi, Enerji Yönetim Sistemi.

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Highlights

- Energy efficiency for data centers
- European green deal goals for data centers
- Data center key performance indicators
- Customized energy management system for data centers

1. INTRODUCTION

Several factors will continue to push the development of smaller, building-integrated data centres forward. Among these are the roll-out of 5G and the shift to SDN[1], the increase in network density, which makes it more advantageous to have data centres as part of buildings, the expansion of Cloud Gaming, and real-time data processing for IoT (Internet of Things) devices, and so on. As a result of the ra-

[1] Software Defined Networks

pid expansion in units and energy consumption, data centres are predicted to have the fastest rising carbon footprint throughout the whole ICT (Information and Communications Technology) industry, accounting for 5-9% of global electricity consumption and more than 2% of global greenhouse gas emissions. If unchecked, ICT emissions could account for 14% of world emissions by 2040 [1].

Carbon emissions are the main reason for human-influenced climate change which has increased over the past few years. Carbon emissions and climate change are the main causes of melting glaciers and polar ice, acid rain, smog, urban air pollution, ocean acidification, and many other harms to nature. The increased usage of carbon has several negative consequences, including increasing climate change. Many causes contribute to the rise in global carbon emissions, particularly buildings that grow as technology advances, such as data centres, which play a key role in raising carbon emissions. EMS[2] (Energy Management System) is a possible solution for this problem, since EMS monitors energy usage performance, helps increasing efficiency, enables full dependence on RES (Renewable Energy Sources), decreases overall energy consumption, and because of the energy-saving potential of edge data centres.

To reach the goal of making data centres more efficient and sustainable, Guitart suggested a comprehensive plan to lower the carbon footprint of data centres that employ energy as a driver of their management operations [2]. Furthermore, a holistic management architecture for sustainable data centres was built, and design recommendations to execute each stage of the planned strategy were given, referring to relevant successes and enumerating the key problems that must yet be overcome. Shriram et al propose a smart system that leverages the Internet of Things to collect data and a machine learning algorithm for decision-making to reduce energy usage in data centres [3]. On the other hand, Basmadjian looked at data centre management from two perspectives: minimizing overall energy use and lowering peak power during demand-response periods. Moreover, potential data centre methods that allowed flexibility in conjunction with flexible contracts, such as green service levels and supply-demand agreements, were examined [4].

Aujla and Kumar present an effective strategy for energy management with the sustainability of Cloud Data Centres in Edge-Cloud Environments utilizing SDN (Software Defined Networks) to achieve energy efficiency and optimal usage of network and computing resources [5]. On the other hand, Zhang et al explored the challenge of energy management for geo-distributed data centres using renewable resources and energy storage. By utilizing the spatiotemporal variability of these system states, the goal was to reduce long-term operation costs such as power costs, water use, and carbon emissions by formulating the cost minimization problem as

2 Energy Management System

a stochastic optimization problem and then adopting the Lyapunov optimization technique to design a close-to-optimal algorithm to achieve a trade-off between system cost and performance of delay tolerant workloads [6].

Previous successful experiences reveal that energy efficiency measures for green data centres were either not appropriately coupled to maximize outcomes, or they were mainly focused on the design stage of data centres, necessitating big upfront investments at the start of a new construction. The ECO-Qube concept combines currently tested energy-saving technologies in a dynamic framework that allows new and existing data centres to decrease their energy usage.

The EMS developed by Endoks is one of the main parts of ECO-Qube's holistic approach for data centres, since it collects and monitors the data centre's energy production and consumption, in addition to calculating, monitoring, and reporting KPIs (Key Performance Indicators) which enables data centre owners to track and recognize their energy usage efficiency, carbon footprint, energy savings, energy consumption patterns, upgrade potential, and system flaws. Moreover, it allows data centres to compare KPIs with green goals set by data centres, and therefore, it enables taking fast action to get back on track in case of any problem.

2. MATERIAL AND METHODS

Developing ECO-Qube EMS was done in 6 main steps. In the first step, ECO-Qube KPIs have been investigated, and the necessary formulas to calculate them have been prepared. The second step and one of the most important steps was creating a signal list to identify the data required from data centres to calculate the project's KPIs[3]. The third step was mapping these signals to the data centre's data aiming to be able to calculate KPIs correctly. The fourth step was to create a user interface for real-time monitoring of data centres and their KPIs. The fifth step was integrating the prepared formulas and signals received from data centres into the user interface. The sixth and last step is integrating ECO-Qube EMS into BEMSs (Building Energy Management System) of the data centres. This interface will facilitate communication between ECO-Qube EMS and BEMS[4] which allows BEMS to receive KPI information, energy consumption suggestions, emergency alarms, and even control signals from ECO-Qube EMS if required.

An energy management system (EMS) is a set of computer-aided tools used by electric utility grid operators to monitor, regulate, and improve the operation of the generating or transmission system. It is also employed in small-scale systems such as microgrids. The main objective of an EMS is to monitor and control energy sys-

[3] Key Performance Indicator
[4] Building Energy Management System

tems. There are many benefits of using an EMS in microgrids such as accelerating system faults handling which minimizes the effects of these faults by decreasing economical loss and increasing the system's reliability. Other benefits of using an EMS are energy saving, environmental protection, and future planning. Energy management systems track energy consumption, which helps users to decrease their energy consumption and reduce operating costs, moreover, EMSs can also monitor and control renewable energy production which is useful for microgrids with local production. The main usage areas and benefits of EMS are as below:

- Energy data acquisition, storage, and management: Data management is the main task of energy management systems. Since a significant amount of data needs to be gathered (within a short time interval) for optimum energy management, there is a huge importance of data management.

- Reducing operating costs and improving productivity: There are a lot of factors that affect the costs and productivity of energy systems since even a shadow can affect the whole system. EMS plays an important role here in the optimization of these points based on information analysis.

- Accelerating system fault handling: One of the biggest roles of an EMS is to realize the operation dynamics of the system and be able to observe and act to fix the failures according to that concept. An important advantage of the EMS is helping to determine the failures' context and magnitude.

- Energy saving and environment protection: One of the most important usage areas of EMS is energy saving and environment protection. Many people have begun to realize the consequences of global warming and climate change which are taking place because of high CO2 emissions since the industrial revolution. As this awareness is increasing, environmental-saving actions should be taken. Energy management systems provide an opportunity for effective actions. EMS's main role is to monitor and control energy systems to improve energy usage efficiency and decrease overall energy consumption. The benefits of energy management systems are not only environmental but also economical. Energy management systems also provide an infrastructure for wide renewable energy integration. EMS plays a main part in the future of energy since its usage can be universal for all kinds of systems.

- Future planning: Energy management systems collect data to calculate KPIs and sketch illustrative graphs of energy systems' performance, which enables effective future planning considering environmental and economical profits.

2.1. ECO-Qube EMS

Several approaches like using more efficient cooling systems, heat reuse, and use of renewable energy to supply data centres can be used to achieve energy efficiency goals for data centres. EMS can be used as a tool to enhance energy efficiency and is one of the most important parts of the solution for the energy efficiency of data centres. It will be possible to monitor and control both produced and consumed energy within the data centre ecosystem with a holistic approach with ECO-Qube EMS which is developed in accordance with SAREF[5] standards.

According to SAREF standards, this energy usage and power data are shared and controlled interactively. Moreover, ECO-Qube EMS can integrate other energy systems to regulate energy demand and supply for data centres using SAREF and worldwide communication standards. Supporting sustainability is a prioritized goal for ECO-Qube's smart energy management system (ECO-Qube EMS), which is designed to measure energy demand and run the energy supply in collaboration with the building/district's EMS (if applicable). This synergy enhances the energy supplied by renewable energy sources on the one hand and minimizes the energy supplied by sources with a high carbon footprint on the other.

ECO-Qube EMS is a unique smart energy management system that can interface with the building's energy management system (BEMS) to regulate and manage the energy-related components within the data centre facility. Figure 1 illustrates the integration strategy as envisaged in ECO-Qube.

Figure 1. ECO-Qube architecture [7]

5 The Smart Applications REFerence

A traditional EMS works as explained in the previous paragraphs, but ECO-Qube EMS is customized for data centres, this customization is mainly done by including KPIs used for energy efficiency in data centres.

The ECO-Qube EMS monitors the data centre's energy use and stores historical logs. After reading the energy demand, the EMS system reads the immediate PV generation and remaining battery power via the building/energy grid's EMS system. The EMS has both monitoring and controlling functions. One of the vital properties of the EMS "energy saving and environment protection". The EMS can monitor and control real-time energy consumption and production and provide energy optimization so that it can be used as a tool to reduce the energy consumption of data centres.

2.2. ECO-Qube KPIs

Most data centres presently have little or no capability for tracking energy use or environmental effects. Many residences do not have a separate utility meter or bill. ECO-Qube will use its smart energy management system, which will be fully integrated with the existing building's EMS, to control and measure real-time consumption and performance of the data centre directly from IT (Information Technology) devices, as well as detect the flow of recovered heat that can be used in the local district heating system. This will let all level end users acquire PUE[6], REF[7], ERF[8], PES[9], CO2 Savings, and PPW[10] values through a simple user interface, allowing them to gain a better understanding of data centre energy consumption trends, efficiency upgrade possibilities, and system problems.

The ECO-Qube KPIs, in particular, comply with the "2021 Best Practice Guidelines for EU Code of Conduct on Data Centre Energy Efficiency," which is regarded as the key reference in this industry since it is one of the most extensive studies in this sector [8].

The EN 50600 standard, on the other hand, indicates that the fundamental goal of KPIs is effective resource utilization, such as decreasing energy consumption, enhancing IT load efficiency, reusing unconsumed resources, utilizing renewable energy, and so on [9]. ECO-Qube aims to achieve this goal by measuring and reporting key KPIs; the usage of these KPIs aligns with both the EU code of conduct and EN 50600 requirements, such that the majority of the KPIs used in ECO-Qube are recommended by both EN 50600 and the EU code of conduct [8].

6 Power Usage Effectiveness
7 Renewable Energy Factor
8 Energy Reuse Factor
9 Primary Energy Savings
10 Performance Per Watt

The KPIs used in ECO-Qube are available in detail in D6.1 [10] of the ECO-Qube project, and they are summarized as follows:

1. PUE (Power usage effectiveness): A parameter that is frequently used to describe data Centre efficiency. It relates the total energy consumption of a data Centre to the energy consumption of IT equipment.

$$PUE = \sum_{i}^{n} \left(\frac{EDCi}{EITi} \right) \tag{1}$$

$EDCi$: Total data centre energy consumption in the period of time i.

$EITi$: IT equipment energy consumption during the period of time i.

2. REF (Renewable Energy Factor): REF is a quantitative metric for the use of renewable energy in the form of electricity in a data centre.

$$REF = \frac{\sum_{i}^{n} \left(E_{DC\ grid-used\ i} * \frac{E_{ren\ i}}{E_{tot\ i}} + E_{DC\ ren\ onsite\ i} + E_{DC\ ren\ cert\ i} \right)}{\sum_{i}^{n} \left(E_{DC\ i} \right)} \tag{2}$$

$EDCi$: Total data centre energy consumption in the period of time i.

$E_{DC\ grid-used\ i}$: Energy provided from the grid and consumed in a data centre during the period of time i.

$\frac{E_{ren\ i}}{E_{tot\ i}}$: Renewable energy fraction of the total grid energy (provided by the supplier) in the period of time i.

$E_{DC\ ren\ onsite\ i}$: Renewable energy generated on-site and consumed in the data centre in the period of time i.

$E_{DC\ ren\ cert\ i}$: RE obtained by procurement of RE certificates and retired in the data centre in the period of time i.

3. ERF (Energy Reuse Factor): ERF provides a way to determine the factor of energy reuse outside the data centre. It is defined as the proportion of energy reused divided by the total amount of energy consumed in a data centre.

$$ERF = \sum_{i}^{n} \left(\frac{EReusei}{EDCi} \right) \tag{3}$$

$EDCi$: Total data centre energy consumption in the period of time i.

$EReusei$: Reused energy and utilized for beneficial purposes in the period of time i.

4. PES (Primary Energy Savings): Primary Energy Savings indicator describes the change in the data centre energy profile after upgrading the data centre equipment or after the introduction of flexible environmental, energetic, and economic improvement in the data centre energy profile.

$$PES = \frac{\sum_{i}^{n} ((EDCi + EothDCi)\ bas - (EDCi + EothDCi)\ cur)}{\sum_{i}^{n} (EDCi + EothDCi)\ bas} \tag{4}$$

$(EDCi)_{bas}$: Total data centre energy consumption in the period of time i before upgrading the DC.

$(EDCi)_{cur}$: Total data centre energy consumption in the period of time i after upgrading the DC.

$(EothDCi)_{bas}$: Total primary energy produced from other sources in period of time i before upgrading the DC.

$(EothDCi)_{cur}$: Total primary energy produced from other sources in period of time i after upgrading the DC.

5. CO2 Savings: CO2 Savings is the % of savings in terms of CO2 emissions associated with DC operations.

$$CO2\ Savings = \frac{\sum_{i}^{n} ((CO2ei + CO2othi)\ bas - (CO2ei + CO2othi)\ cur)}{\sum_{i}^{n} (CO2ei + CO2othi)\ bas} \tag{5}$$

$(CO2ei)_{bas}$: Total CO2 emissions released by the DC consumed energy in the period of time i before upgrading the DC.

$(CO2ei)_{cur}$: Total CO2 emissions released by the DC consumed energy in the period of time i after upgrading the DC.

$(CO2othi)_{bas}$: Total CO2 emissions released by the energy produced from other sources in the period of time i before upgrading the DC.

$(CO2othi)_{cur}$: Total CO2 emissions released by the energy produced from other sources in the period of time i after upgrading the DC.

6. PPW (Performance Per Watt): The performance per watt of computer architecture or computer hardware is a measure of its energy efficiency. It quantifies the pace of calculation that a computer can deliver for every watt of electricity consumed.

$$PPW = \frac{\sum_{B=i*y}^{n*y}\left(\frac{BOPS_B * CPU\ Utilization_B}{Energy\ Consumption_B}\right)}{(n-i)*y} \tag{6}$$

$BOPS_B$: Billion Operations Per Second.

$CPU\ Utilization_B$: Server CPU utilization.

$Energy\ Consumption_B$: Energy consumed by the server.

i : KPI calculation start point (No. of interval).

n : KPI calculation endpoint (No. of interval).

y : No. of seconds in each interval.

B : KPI calculation start time.

ECO-Qube EMS is designed to track the energy demand, operate the energy supply in cooperation with the building/district's EMS, and calculate the KPIs listed above since the calculated KPIs can be shown on the user interface of the EMS. ECO-Qube EMS can monitor all production, consumption, and energy storage. The EMS also has historical data visualization, detection of abnormal values, and automatic alarm activation functions. KPI calculations are done by using formulas 1 – 6. To calculate PPW, it is assumed that the total time interval is divided into equal sub-intervals, where is the first sub-interval and is the last sub-interval taken into consideration. In addition, ECO-Qube EMS can provide data needed by the ECO-Qube AI (Artificial Intelligence) container engine. ECO-Qube EMS provides communication options such as Modbus TCP/IP, IEC 60870-5-104, and API (Application Programming Interface) communication protocols.

3. RESULTS AND DISCUSSION

ECO-Qube EMS user interface was designed by Endoks to enable data centre owners to view their assets and KPIs in real-time, in addition to providing a graphical representation of the data, automatic alarms, and many other features as will be seen in the following parts.

Figure 2 shows the preliminary design of a data centre's EMS's SLD (Single Line Diagram) in the user interface. This structure can be subject to some additions such as control options, constant input for KPI calculation, etc. Graphical representation of energy production and consumption, battery discharge, and other data will also be shown in the user interface as shown in Figure 3.,

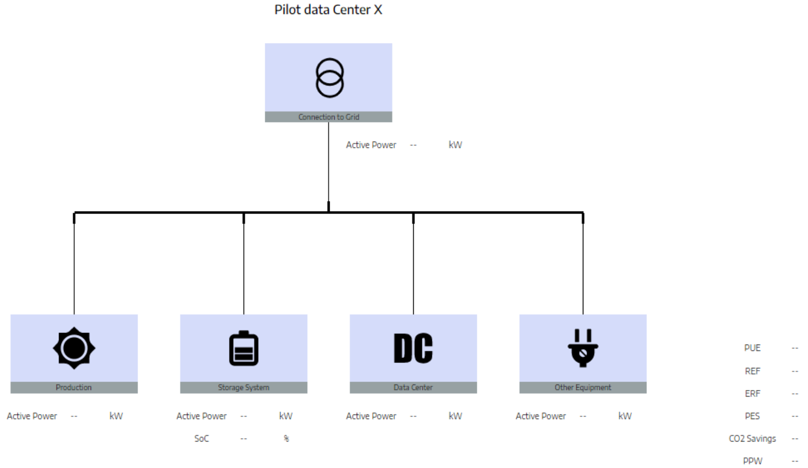

Figure 2. ECO-Qube EMS SLD UI preliminary design

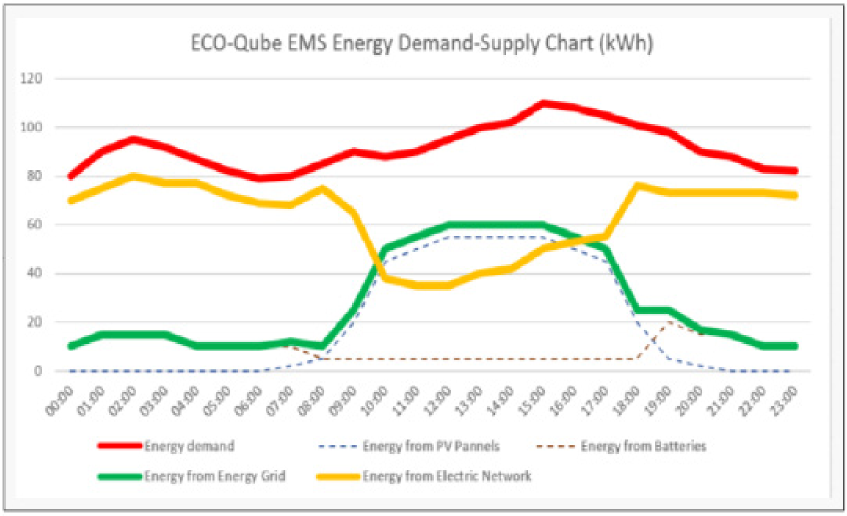

Figure 3. Graphical representation of the data centre's data

There is a welcome page that shows the overall energy flow at the EMS and alarms can be tracked. Consumption, production, and storage can be investigated at separate tabs on the top left side of the screen. Energy flow, KPI performance, production, consumption, battery charging and discharging, SoC, and grid import/export values and time graphs are also available on this page. Each parameter could be viewed alone or in any combination the user chooses as shown in figure 4.

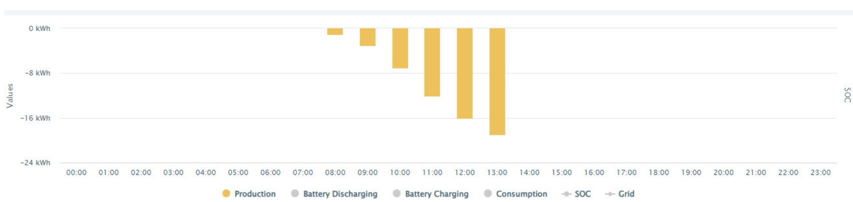

Figure 4. Production graph on the welcome page

ECO-Qube EMS features could be adjusted according to data centres preferences including adding/removing KPIs. Furthermore, new modules could be added easily such as cost-benefit analysis, RES controller, BESS[11] controller, load controller, and electrical utility grid import controller. Another profit of ECO-Qube EMS is that it could be comfortably modified to meet other sectors' needs where energy monitoring and efficiency are required, which is a very important advantage sin-

[11] Battery Energy Storage System

ce it provides an economical – clean energy solution. This solution will motivate individuals and businesses to decrease their carbon footprint, especially in the following years when variable tariff systems are expected to be applied all around the world and therefore, achieve global green goals.

4. CONCLUSION

The need for data centres is expected to increase due to technological advances. This increase directly causes the data centre's carbon footprint to increase. Edge data centres are more suitable than traditional large-scale data centres since edge data are faster because of their near location. Moreover, edge data centres have high energy-saving potential, which makes them a perfect target for optimization through a holistic approach. Endoks took an important part in this holistic approach by developing a smart EMS. The UI (User Interface) developed within the ECO-Qube project delivers advanced monitoring and control functions, which enables data centres to observe consumption comprehensively based on smart metering hardware used in data centres. Moreover, all data integrated into ECO-Qube EMS can be represented graphically along with calculated KPIs. This data and KPI values could also be reported and compared with the historical records, which is another important feature of the EMS. All these features provided by Endoks's local UI show beyond doubt that ECO-Qube EMS provides a chance for data centres to operate more efficiently. ECO-Qube has proven that the key to achieving low or even zero carbon footprint goals could be achieved by utilizing detailed monitoring and control of energy consumption. Finally, the ECO-Qube EMS is a very useful tool which can be used for energy efficiency by data center owners and has an awareness-raising effect about both energy efficiency and carbon footprint.

Acknowledgement

The Eco-QUBE EMS developing activities have been realized within "Artificial-Intelligence-Augmented Cooling System for Small Data Centres (ECO-Qube)" and has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.956059.

*The co-author acknowledges the support given by the Scientific and Technological Research Institution of Türkiye (TÜBİTAK) under project agreement No.119C128.

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