SECURE DATA UTILIZATION FROM PHOTOVOLTAIC SYSTEMS FOR OPTIMIZATION PURPOSES

BIZTONSÁGOS ADATKEZELÉS NAPELEMES RENDSZEREK OPTIMALIZÁLÁSÁHOZ

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Abstract

As the global push for more sustainable energy sources gains momentum, solar energy adoption is becoming increasingly significant. This research deals with the complex challenges that a special category of producers of electric energy from solar power, an individual producer - consumer encounters. More specifically, the research focuses on electric energy production-distribution-consumption data extraction, independently from the available data recorded and stored by the installed photovoltaic systems, and the suppliers of electric energy. The independent data extraction enables safe long-term data storage, and a possibility to perform different calculations enabling the optimization of the elements of the photovoltaic systems regarding their structure and capacity. The initial part of the research offers an overview of independent data extraction technology. Subsequently, a case study involving a producer-consumer household compares collected data with the photovoltaic system's output.

Keywords

Photovoltaic Solar Energy System, Information Security, Individual Producer – Consumer, Data Extraction, REST API

Absztrakt

Napjainkban világszerte növekszik a fenntarthatóbb energiaforrások alkalmazása, ezért a napenergia hasznosítása egyre fontosabbá válik. A kutatás a napenergiából elektromos energiát termelő, ún. termelő-fogyasztó esetében jelentkező összetett kihívásait vizsgálja, konkrétan, az elektromos energia termelés-felhasználás adatainak kinyerésére összpontosít, függetlenül az adatoktól, amelyeket a napelemes rendszerek, valamint a szolgáltatók rögzítenek és tárolnak. A független adatkinyerés lehetővé teszi a biztonságos hosszútávú adattárolást, és lehetőséget nyújt különböző számítások végrehajtására, amelyek optimalizálják a napelemes rendszerek elemeit és kapacitását. A kutatás bevezető része áttekintést nyújt a független adatkinyerés technológiájáról. Ezt követően egy esettanulmány kerül bemutatásra, ahol egy termelő-fogyasztó háztartás esetében a függetlenül kinyert adatok összehasonlításra kerülnek a napelemes rendszer által bemutatott és használható adataival szemben.

Kulcsszavak

Napelemes Rendszer, Információ Biztonság, Egyéni Termelő – Fogyasztó, Adatkinyerés, REST API

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INTRODUCTION

Solar energy has raised considerable attention as a renewable and sustainable form of electricity, not just within industrial facilities like electric energy production, but also among individual households. With advancements in solar technologies and growing environmental concerns, numerous studies have delt with the feasibility, advantages, and obstacles linked to adopting solar energy at the household level.

Researchers have pointed out that solar energy systems can yield long-term cost savings in comparison to traditional electricity sources, by lowering energy costs, and offering returns on investment over time [1, 2]. Additionally, solar energy adoption contributes to the reduction of greenhouse gas emissions and dependence on non-renewable energy sources, promoting sustainability [3, 4].

Also, recent advancements in solar energy system technologies have significantly improved the efficiency and effectiveness of residential solar systems. The development of high-performance solar panels, advanced tracking systems, and energy storage solutions, enhance the overall performance of individual household solar systems [5]. These advancements have increased the feasibility and attractiveness of solar energy adoption in individual households [6].

The economic feasibility of solar energy adoption in individual households has been extensively studied too. Research suggests that the cost-effectiveness of solar systems is influenced by factors such as government incentives, the availability of net metering programs, and the cost of alternative electricity sources [7, 8, 9, 10, 11]. Studies have also emphasized the importance of accurately assessing the financial benefits and payback periods associated with solar energy systems [12, 13]. Optimization of solar systems and the use of information and communication technologies (ICT) in the process is also an issue that has been delt with in literature [14, 15].

The environmental benefits of solar energy adoption in individual households are well-documented as well. Solar energy systems generate clean and renewable energy, reducing carbon emissions and mitigating climate change [16, 17]. Additionally, the use of solar energy in individual households can contribute to the overall sustainability of the electricity grid by reducing peak demand and promoting decentralized power generation [18].

Despite the numerous advantages of using solar energy in individual households, several challenges and barriers must also be addressed. Researchers have highlighted issues such as system intermittency, limited rooftop space, high upfront costs, and complex installation processes as potential obstacles to widespread adoption [19, 20, 21]. Additionally, policy and regulatory frameworks, grid integration challenges, and public perception can affect the rate of solar energy adoption [22].

This points towards the presented research, which aims at providing valuable insights into the technology of independent electric energy production-distribution-consumption data extraction in the case of individual producers – consumers. This would enable for the safe and secure data storage with no dependency on the installed photovoltaic systems (PVS), and the supplier of electric energy. Moreover, this would assure the possibility of performing different calculations enabling the optimization of the elements of the PVS regarding their structure and capacity.

We are witnessing that nowadays web information systems are most developed as integrated web systems composed of several different components. These systems typically consist of: a multi-platform web application (front-end part serving as a presentation platform), web application and/or services (back-end part for performing all necessary operations crucial for the system's functioning, administrative section), a mobile application (with capabilities either different or similar to the web application on the front-end but designed for intuitive use on mobile devices), and REST or RESTful API services for data exchange between components of the integrated web system. There are systems that retrieve data from other services via API endpoints, process it, and store it in their own databases. By using this data, they create API endpoints that can be public or require some form of authentication. These newly created API endpoints can then be used in other systems, which will utilize the obtained data in applications tailored to new requirements.

To maintain consistent communication across various devices, components, and platforms, it's essential to format the data using a standardized data format, like JSON (JavaScript Object Notation) or XML (Extensible Markup Language). Researchers compared both standards and provides an in-depth analysis of their performance. The results of each test were analysed and discussed. Overall, JSON outperformed XML in terms of data size and web API response time for all operations, except deletion. In some cases, JSON was 30 to 40% faster than XML, particularly with a growing number of records [23].

JSON format can be quickly parsed and generated by programming languages. Most programming languages provide built-in support or libraries for working with JSON, but the performance of JSON parsers varies with their implementation. In [24] performance analysis of JSON parsers in the native environment of 5 different programming languages has been conducted in terms of parsing speed and resource consumption.

The server can authenticate each client through cookies or session on the HTTP protocol using REST API. Nonetheless, there is a vulnerability that makes it easy for a hacker to take the identification information, such as tapping the broadcast packets or employing a fake proxy or other tool for this purpose. In research [25], a new mechanism called disposable token is proposed, which is based on token authentication of RESTful API on the HTTP protocol. The client is requested to store the public and private token-pair computed by the server as part of this mechanism.

In the following paragraphs, the proposed ICT technologies for data extraction will be presented, followed by a case study showing the extracted data compared with the data from the installed PVS regarding the energy production, direct consumption, distributed energy towards the grid, as well as taken energy from the grid. Following this, a short discussion and conclusions will be presented.

Data extraction

The photovoltaic system has its own web panel where, through logging in with valid credentials, current data for the installed system can be viewed. The web panel is used for data visualization, and data can be filtered based on certain criteria. To use the data from the PVS for optimization calculations, it is necessary to extract them from the system by applying ICT (Information and Communication Technology) technologies. It can be done with various technologies.

In our case, the extraction of data was done using the PHP programming language, version 8, with the JSON Machine class. PHP (Hypertext Preprocessor) is a server-side scripting language designed for web development to create dynamic and interactive web pages. PHP 8 introduced several features and improvements aimed at enhancing speed and execution performance. It includes a JIT compiler, which stands for Just-In-Time compilation. This feature can improve the performance of certain types of applications by dynamically translating PHP bytecode into machine code at runtime, potentially resulting in faster execution.

JSON Machine is a parser based on generators designed for handling JSON streams or documents that may be unpredictably long. It is efficient, user-friendly, and offers fast processing capabilities. The extracted data is stored in the MySQL relational database.

The creation of HTTP requests was done using the cURL (Client URL) library. In PHP, cURL is a library and command-line tool used for making HTTP requests, interacting with various protocols, and retrieving or sending data to remote servers. It provides a versatile set of functions that allow developers to work with URLs, handle cookies, set various options for HTTP requests, and perform actions like GET, POST, PUT, or DELETE. cURL is commonly used for tasks such as fetching API data, making HTTP requests, and interacting with web services.

Case study

The case study presented is based on a producer – consumer household that produces electric energy by using a PVS with a total string capacity of 12kWp (32 modules – Mono-crystalline – CHSM60M-HC (BF) 166), with a 10KW inverter (SUN2000-10KTL-M1) and with no storage.

For the case study, the following data was extracted:

- Produced electric power from PVS (PEPPVS) [kW],
- Totally consumed electric power (TCEP) [kW],
- Directly consumed electric power from PVS (DCEPPVS) [kW],
- Electric power transferred to the grid from PVS (EPTGPVS) [kW],
- Electric power transferred from the grid for consumption (EPTGC) [kW].

Based on the extracted data, the following data was calculated:

- Produced electric energy from PVS (PEEPVS) [kW/h],
- Totally consumed electric energy (TCEE) [kW/h],
- Directly consumed electric energy from PVS (DCEPPVS) [kW/h],
- Electric energy transferred to the grid from PVS (EETGPVS) [kWh],
- Electric energy transferred from the grid for consumption (EETGC) [kWh].

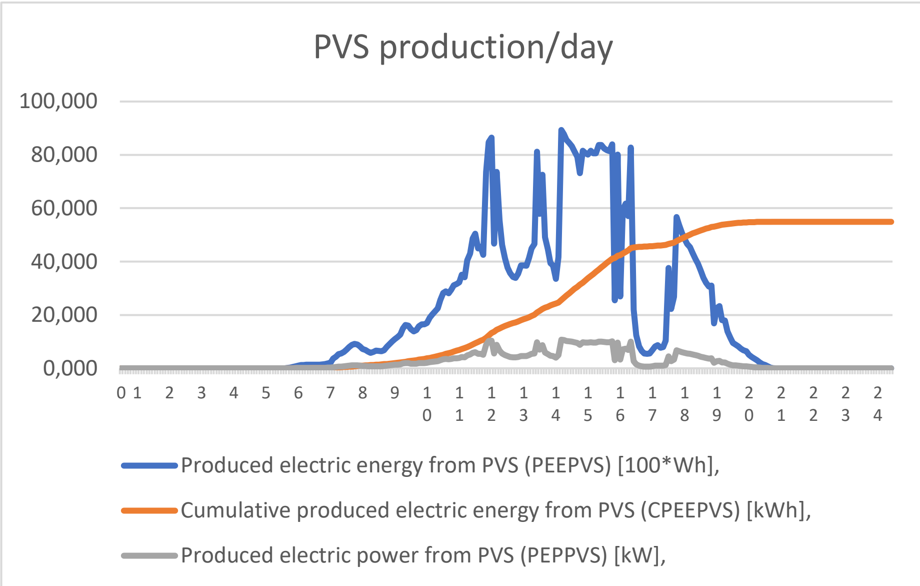
Also, the cumulative values of the energy amounts were calculated as well:

- Cumulative produced electric energy from PVS (CPEEPVS) [kW/h],
- Cumulative totally consumed electric energy (CTCEE) [kW/h],
- Cumulative directly consumed electric energy from PVS (CDCEPPVS) [kW/h],
- Cumulative electric energy transferred to the grid from PVS (CEETGPVS) [kWh],
- Cumulative electric energy transferred from the grid for consumption (CEETGC) [kWh].

The data was automatically extracted indirectly from the data provided by the installed PVS. The used time step was 5 minutes. For the study, the data was extracted for 12 months, however due to the extensive amount of information, only part of the data for one day, namely for May 27, 2023, is presented in the paper.

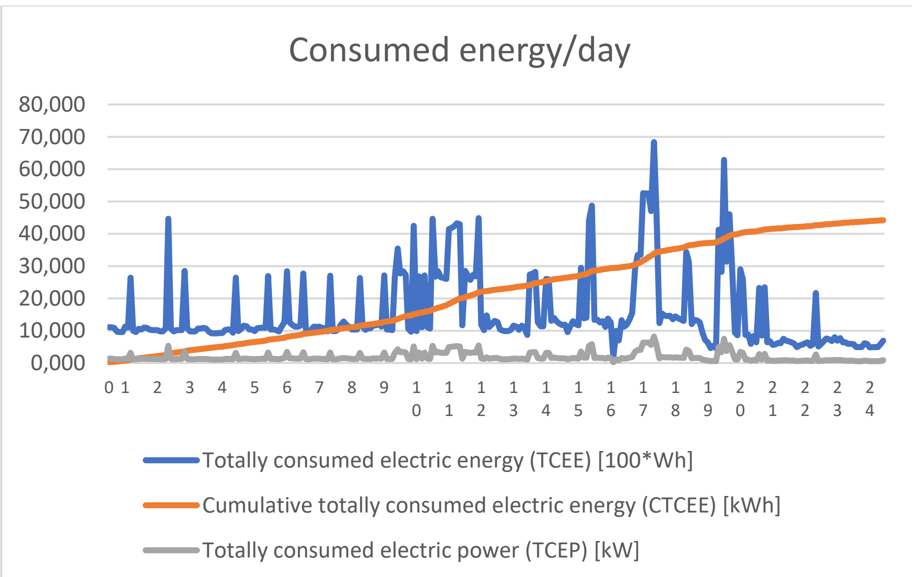
In the following figures, the extracted and calculated values are presented.

In Figure 1, the PEPPVS, PEEPVS and CPEEPVS are presented.



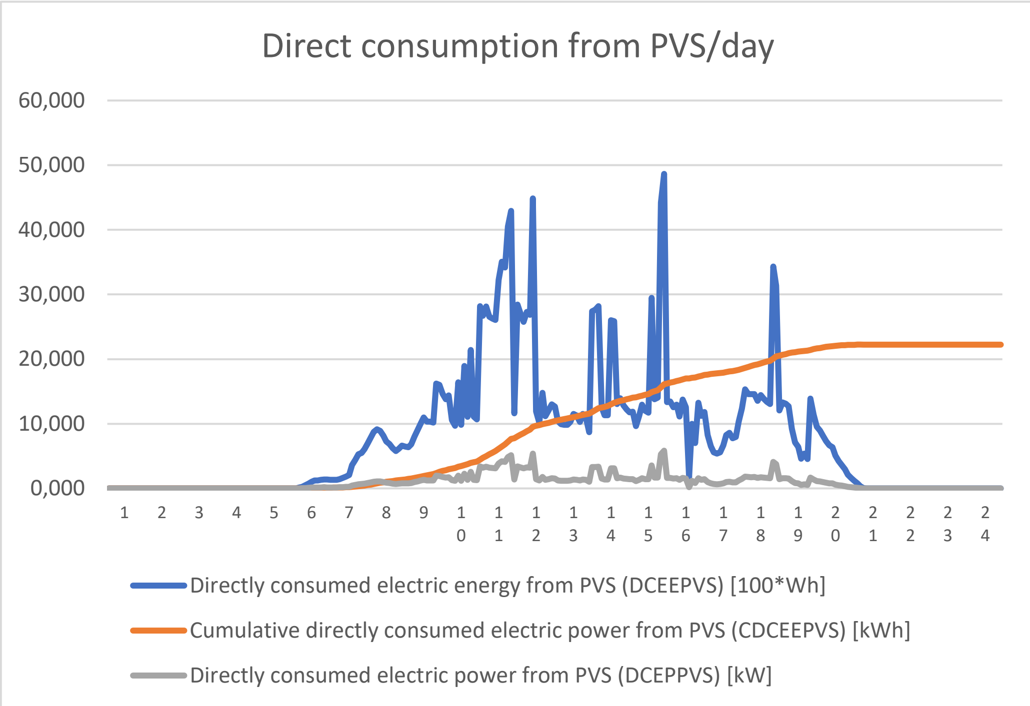
1. Figure: PVS production for one day (May 27, 2023)

In Figure 2, the TCEP, TCEE and CTCEE are presented.



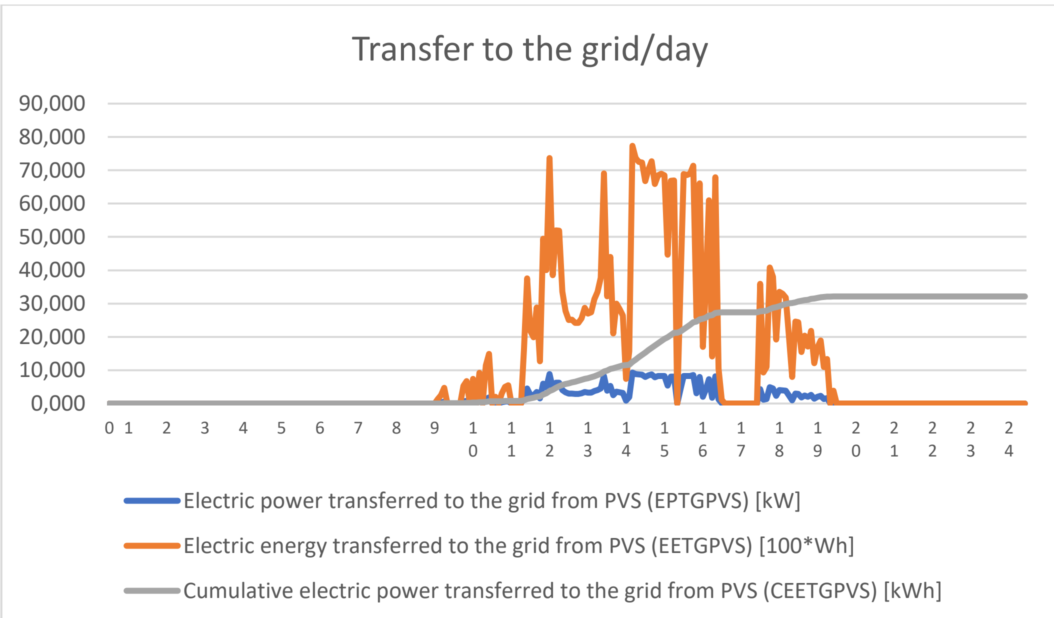
2. Figure: Total energy consumption for one day (May 27, 2023)

In Figure 3, DCEPPVS, DCEEPVS and CDCEEPVS are presented.



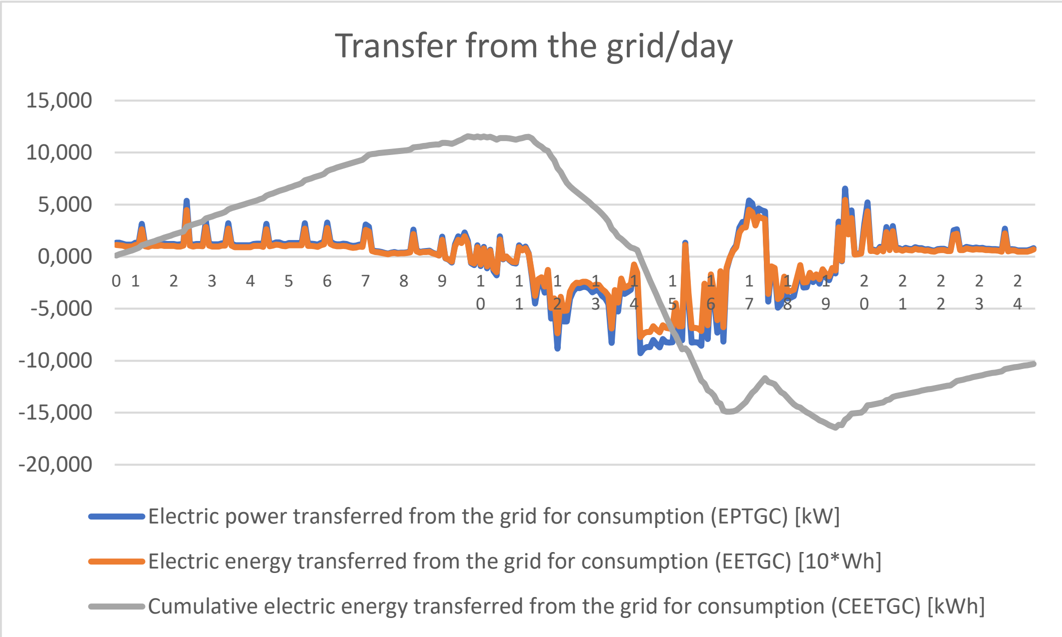
3. Figure: Direct consumption from PVS for one day (May 27, 2023)

In Figure 4, EPTGPVS, EETGPVS and CEETGPVS are presented.



4. Figure: Energy transfer from PVS to grid for one day (May 27, 2023)

In Figure 5, EPTGC, EETGC and CEETGC are presented.

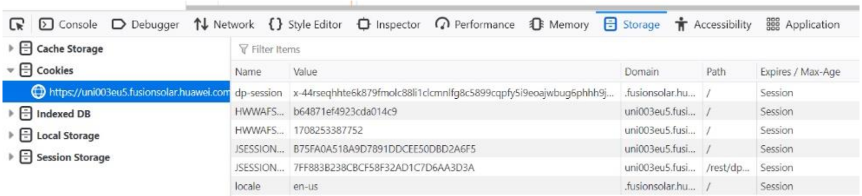


5. Figure: Energy transfer from grid to consumer for one day (May 27, 2023)

It can be noted that there are positive and negative values in Figure 5. Positive values refer to the situation when the total consumption is higher than the production from the PVS, while negative values refer to the situation when the total consumption is lower than the production from the PVS, and then the excess energy from the PVS is distributed to the grid.

Discussion

The data provided by the installed system to the user interface is formatted in JSON format and accessible through REST API endpoints. Access to this data is not public and requires a valid user to be logged into the system. To retrieve and store this data in another database, it was necessary to determine the authentication method. For the analysis of HTTP headers, Web Developer Tools were used, which exist in all modern web browsers. These tools offer multiple options, with Network and Storage being the most used. Through the Network option, information about HTTP requests and responses can be determined. Key information includes the URL of the request, parameters sent with the request, request body, HTTP headers, as well as the method and type of request. After receiving the response, an analysis was conducted on the parameters obtained in the response: HTTP headers and cookies. A detailed analysis of the response through the Storage option provided insight into cookies related to the site's operation and session cookies created after successful login to the system.

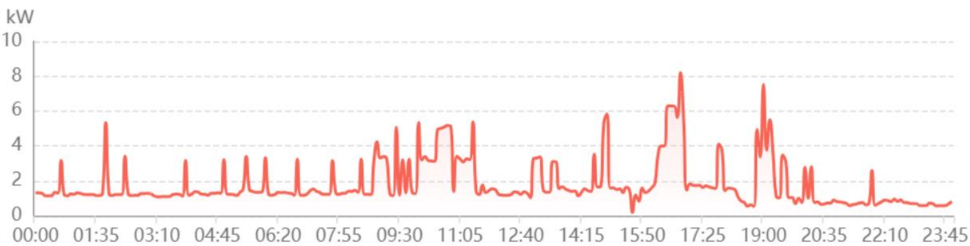


6. Figure: Web Developer Tools – Storage tab

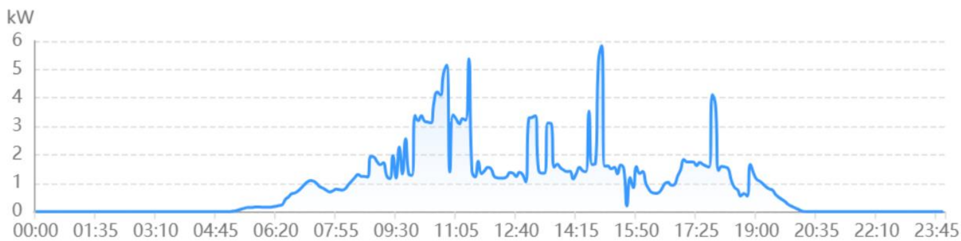
To verify the availability of API endpoints, requests were tested by sending data from HTTP headers and cookies. Postman and ReqBin tools were used for testing purposes. After successful tests and data retrieval, a program code was created to automatically send requests for a specific date. The program code utilized the cURL library. The desired data, obtained in JSON format, was parsed, and stored in a database. Retrieving data for the specified date was possible because the request included not only valid data from HTTP headers and cookies but also a parameter for the required date.

To be able to reflect on the data obtained and calculated, it is necessary to present the data available directly from the PVS. There is a possibility to present a certain type and amount of data, namely the PEPPVS (Fig. 7), TCEP (Fig. 8), and DCEPPVS (Fig. 9).

7. Figure: PVS production power for one day (May 27, 2023)



8. Figure: Total consumption power for one day (May 27, 2023)



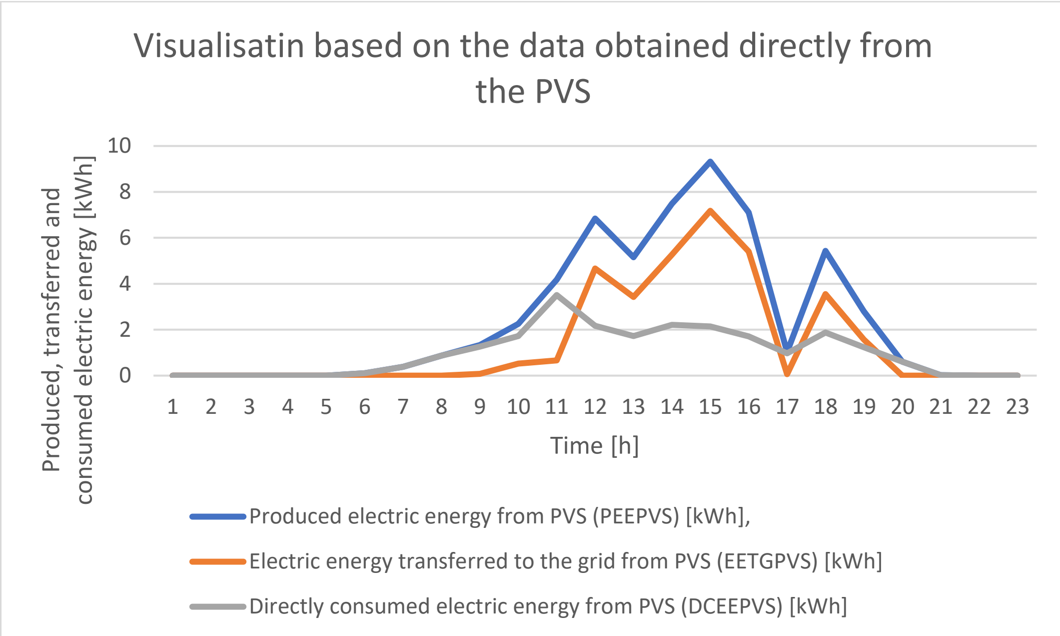
9. Figure: Direct consumption power from PVS for one day (May 27, 2023)

If the data presented in Fig. 1, Fig. 2, and Fig. 3 are compared to those presented in Fig. 7, Fig. 8, and Fig. 9, it can be concluded that the data patterns are similar. However, the data obtained directly from the PVS can only be used for visualization purposes. There is a possibility to obtain data from the PVS, but this possibility is rather limited. The data can be obtained only for whole hours, and for PEEPVS, EETGPVS, and DCEEPVS. This is presented in Table 1, while the visualization is presented in Fig. 10.

Time [h]	**Produces electric energy from PVS (PEEPVS) [kWh]**	**Electric energy transferred to the grid from PVS (EETGPVS) [kWh]**	**Directly consumed electric energy from OVS (DCEEPVS) [kWh]**
0	0	0	0
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0.1	0	0.1
6	0.39	0	0.39
7	0.88	0	0.88
8	1.34	0.08	1.26
9	2.25	0.52	1.73
10	4.18	0.67	3.51
11	6.84	4.67	2.17
12	5.15	3.42	1.73
13	7.48	5.27	2.21
14	9.32	7.18	2.14
15	7.11	5.4	1.71
16	1.03	0.06	0.97
17	5.43	3.55	1.88
18	2.8	1.57	1.23
19	0.61	0	0.61
20	0.02	0	0.02

21	0	0	0
22	0	0	0
23	0	0	0

1. Table: Data obtainable directly from the PVS



10. Figure: Data visualization based on the data obtained from the PVS

By comparing the data presented in Fig. 1, Fig. 3, and Fig.4 with the data presented in Fig. 10, one can conclude that there are significant differences in the presented data.

CONCLUSIONS

This research on the possibilities of independent data extraction for a PVS in individual households demonstrates the potential for significant benefits in terms of cost savings, environmental impact, and sustainability, based on calculations that could be made by using the extracted data. The presented case study provides valuable insights into the performance of the extracted data and the data from the installed PVS.

Thanks to the analysis of the HTTP communication between the web panel and the PVS, and the retrieval of necessary data for sending valid requests, independent data extraction for the entire year for the installed system has been carried out. ReqBin and Postman tools were used for testing purposes, and the actual extraction program code was implemented using the PHP 8 programming language, along with the JSON Machine and cURL libraries.

The results of the case study show that there are similarities in the visualization of the data obtained indirectly from the PVS, and those visualized by the PVS, but this is limited to visualization purposes only. The data obtained directly from the PVS is rather limited, both in quantity and type of data, and therefore cannot be used for meaningful calculations.

Based on the presented results, it can be concluded that there is a necessity to obtain the data indirectly if one wants to use the data for optimization purposes. This also points towards future research that will use the data for making decisions regarding further development of PVS-s in the case of producers – consumers.

One of the plans is to, after completing the information system for calculating data obtained through independent data extraction from the PVS system, create API endpoints that would be protected by disposable tokens. These API endpoints would be utilized by a mobile application designed to facilitate the viewing of obtained data and calculations in a simple and intuitive manner.

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