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Figures

List of abbreviations

Abbreviation	Definition
AC	Alternative current
BAT-E	Battery energy usage during smart charging sessions
BDF	Battery demand flexibility
BESS	Battery energy storage system
BMS	Battery management platform
CO2	Carbon dioxide
COP	Coefficient of Performance
CPO	Charge point operator
DAMP	Market clearing price
DC	Direct current
DER	Distributed energy resource
DR	Demand response
DSO	Distribution system operator
EMS	Energy management system
ESS	Energy storage system
EPA	Environmental Protection Agency
EV	Electric Vehicle
EVDF	Electric vehicle demand flexibility
FAI	Flexibility Availability Index
FDR	Flexibility Deviation Ratio
FDR	Flexibility Delivery Rate
GR-E	Grid energy usage during smart charging sessions
GTB	Building management platform
GTBatt	Batteries management platform
GTE	Energy management platform
GTR	CO2 network installations management platform
HP	Heat pump
HTML	Hypertext Markup Language
HV	High voltage
ICE	Internal combustion engine
IoT	Internet of Things
Kg	Kilogram
KPI	Key Performance Indicator
LCOE	Levelized Cost of Energy
LCOS	Levelized Cost of Storage
LV	Low voltage
MW	Megawatt
MYTM	Milli yük tevzi merkezi

OCPP	Open charge point protocol
P2P	Peer to peer
PFC	Primary frequency control
PFR	Predicted Flexibility Reliability
PID	Proportional integral derivative controller
PPR	Peak Power Reduction
PV	Photovoltaics
R&D	Research and development
RES	Renewable energy system
SoC	State of Charge
SOEC	Solid oxide electrolyser cell
SOFC	Solid oxide fuel cell
TSO	Transmission system operator
V1G	Uni-directional smart charging
V2G	Vehicle to grid

Contents

Abstract

This report presents a comprehensive assessment of flexibility demonstrations conducted in Turkey and Switzerland, focusing on the benefits, drawbacks, and lessons learned from these test cases.

The objective is to evaluate the potential of flexibility in different contexts and provide recommendations for its effective implementation. The evaluations consider various key performance indicators (KPIs) related to technical, economic, and reliability aspects. The report also examines the market structure and compatibility for flexibility services in both sites.

In the Turkish pilot site, the evaluations demonstrate that electric vehicles and battery storage systems can provide valuable flexibility to the grid, with similar performance levels. Implementing demand-side management and dynamic tariff structures can help reduce grid congestion issues. The report emphasizes the importance of real-time monitoring, advanced control options, and strong communication networks for effective flexibility management. The evaluation is based on the defined KPIs for analysis of the performance of flexibility test cases. It also highlights the significance of regulatory support and defining relationships between stakeholders to enable the proposed business model. The KPIs considered in the studies conducted with the battery storage system, DC EV charger, and V2G charger were calculated in the relevant sections. In the studies, it was observed that the FAI rates of the EV chargers and the battery storage system were close to 100%. Looking at the FDR value, it can be seen that the assets generally responded to the given setpoints at around 99% under normal operating conditions. During the continuous 30-day test conducted with the battery storage system, it was observed that the discharge activities throughout the day reduced the peak load by approximately 8% to 14%. This value is entirely dependent on the battery's maximum discharge capacity, and better results could be achieved with a higher-capacity battery. Likewise, with the DC fast charger, around 30 smart charging sessions were conducted over a 2.5-month period. As a result of these sessions, it was observed that potential peak loads could be limited to around 8% to 35%.

In the Swiss pilot site, the report introduces an evaluation method and defines appropriate KPIs to assess the economic and reliability aspects of flexibility test cases. The assessments consider both qualitative and quantitative analysis, including flexibility costs, remuneration, penalties, revenue, and reliability analysis. The assessment results show the test case with the highest reliability is associated with the battery at 100% availability index (FAI), while the test case with the lowest reliability is linked to the integration of three HPs with a 55% FAI. Moreover, the maximum economic profitability is achieved through the utilization of HPs (HP23 and HP19), generating net revenue percentages of 82.8% and 47.8% respectively, relative to the operational cost.

Overall, this report offers valuable insights into the reliability and economic evaluation of each flexibility test case involving various assets, shedding light on the potential and challenges of flexibility services in the energy sector. By considering the general lessons learned from the evaluations, this report contributes to the effective implementation and management of flexibility, supporting electrification and decarbonization goals in an evolving energy landscape.

Demonstration, final evaluation and lessons learnt

1 Introduction

Flexibility is increasingly important in today's evolving landscape due to the expansion of distributed production sources, electric vehicles, storage systems, and electric heating systems. These technologies are crucial for advancing electrification and achieving decarbonization goals. However, their widespread adoption without proper planning and operation can lead to congestion issues for distribution network operators, adding complexity in the management of energy balancing and distribution. Nevertheless, intelligent management platforms and well-designed business models can mitigate these challenges and even turn them into advantages. Innovative approaches to flexibility offer opportunities for improved energy management and grid optimization in terms of both economics and reliability.

This report aims to comprehensively evaluate the provision of flexibility, focusing on two demonstration activities conducted in distinct areas: the Turkish site (OEDAS) and the Swiss site (HES-SO). These demonstrations provide valuable insights into the potential of flexibility in different contexts. The evaluation encompasses assessing the benefits and drawbacks of flexibility from the perspectives of both the Flexible Service Provider (FSP) and the Distribution System Operator (DSO).

The report begins by developing an evaluation method and KPIs to assess flexibility in accordance with the prevailing circumstances. Test cases representing diverse scenarios are then evaluated, considering both economic and reliability aspects in Swiss pilot site as well as technical, economic and environmental KPIs evaluated for Turkish pilot. Furthermore, the report examines the implementation of flexibility from a market standpoint, assessing the status of flexibility services in the Turkish and Swiss markets. Finally, the report presents a comprehensive analysis of the benefits and drawbacks of flexibility and draws general lessons from the evaluations of different flexibility test cases. This section addresses the opportunities and risks associated with flexibility services, providing proposed mitigations to minimize risks, especially for FSPs.

Overall, this report aims to provide valuable recommendations for the effective implementation and management of flexibility in the energy sector by offering insights into market dynamics, economic considerations, and reliability aspects.

1.1 Scope and Objectives

The primary objective of this report is to assess and evaluate the demonstrations of flexibilities in two flexibility demos conducted in Turkey and Switzerland. The assessment focuses on market, reliability, and KPIs of flexibility test cases. It is also worth mentioning that in each of the following chapters, the test cases related to the sites of Turkish site (OEDAS) and the Swiss site (HES-SO) will be examined separately: first, the Turkish demonstration will be presented, followed by the Swiss demonstration. This approach aims to provide a clear distinction between the perspectives and insights gained from each flexibility demo. In alignment with the objectives outlined in the Grant Agreement, the report aims to achieve the following goals:

- Assessment of flexibility test cases from both FSP and DSO perspectives. In each section of assessment, the respective viewpoints of the FSP and DSO will be examined for the Turkish and Swiss demonstrations, separately.
- The reliability and economic aspects of flexibility tests cases evaluated based on introduced flexibility KPIs.
- Assessment of the compatibility and structure of the market for adapting flexibility services, considering both the current situation and its potential for the future.
- Key conclusions related to the benefits and drawbacks of flexibility services according to the test cases.

2 Test cases evaluation

2.1 OEDAS pilot site

The demo studies conducted in the OEDAS pilot have been evaluated from both the perspective of FSP and DSO. In this context, certain KPIs have been determined to measure the flexibility delivery activities carried out during the demo studies, and these KPIs have been calculated for the assets used in the test cases along with the calculation method. The Technical KPIs have been calculated for different test cases (asset-based) and for the entire system based on their contents. The main purpose of the evaluation is to measure the potential of assets to provide flexibility and their responsiveness to demand, as well as to assess their contribution to reducing the load on the existing transformer in terms of congestion management.

In addition to the technical evaluation, calculations have been made with certain assumptions to enable a simplified economic evaluation. Here, the revenue created by the flexibility provided within the scope of the test case has been taken into account. This revenue has been calculated based on the total cost and delivery rate considered by the asset owner in the flexibility provision process.

Furthermore, in order to determine the contribution of both the installed PV systems in the region and electric vehicle charging systems to reducing carbon emissions, an environmental KPI called "Avoided CO2 value" has been established for the entire system. This KPI serves the purpose of quantifying the environmental benefits in terms of carbon emission reductions that can be achieved through the flexibility provided by these systems.

2.1.1 Evaluation method

i. Technical Evaluation

The fundamental KPIs determined for conducting the technical evaluation are presented below. Subsequently, in Table 2, the KPIs that are considered are presented against the test cases and assets for which they apply.

- **Flexibility Delivery Rate (FDR) (%):** This KPI has been determined to assess the responsiveness of assets to the flexibility request – setpoint created by the DSO (as indicated by the setpoint sent to the asset). It measures the degree to which assets can effectively respond and meet the specified flexibility request from the DSO.

$$FDR = \frac{|Supplied\ Flexibility\ -\ Requested\ Flexibility\ |}{Requested\ Flexibility} \times 100 \tag{1}$$

- **Flexibility Availability Index (FAI) (%):** This index assesses the availability of OEDAS's asset to provide flexibility during flexibility period. It is calculated by dividing the total time that the system is available for flexibility provision by the total time duration of the flexibility period:

$$FAI = \frac{\text{Asset Available Time}}{\text{Flexibility Time Duration}} \times 100 \tag{2}$$

- **Max. Peak power reduction rate (PPR) (%):** This KPI aims to measure the extent to which the peak load in the daily load profile of local DSO transformer can be reduced after the discharging sessions carried out using the smart charging methodology. The objective is to showcase the performance of assets and the proposed method in preventing grid congestion. It provides a clear indication of how effectively the assets and the suggested method can contribute to mitigating grid congestion issues.

$$PPR = ((1 - \frac{|Peak\ Load\ of\ Transformer - Provided\ Flexibility\ Amount|}{Peak\ Load\ of\ Transformer}) \times 100\ ) \quad (3)$$

The above-mentioned KPIs will be calculated individually for each asset (V2G charger, DC charger, battery storage) based on the test cases demonstrated during the demo activities. In addition, the following KPIs will be evaluated for the entire system for a longer-term assessment.

- **Battery demand flexibility (BDF) (kWh):** This KPI will show the flexibility potential provided by stationary battery storage system.

- **Max. Peak power reduction rate (PPR) (%):** This KPI aims to measure the extent to which the peak load in the daily load profile of local DSO transformer can be reduced after the discharging sessions carried out using smart charging methodology. The objective is to showcase the performance of assets and the proposed method in preventing grid congestion. It provides a clear indication of how effectively the assets and the suggested method can contribute to mitigating grid congestion issues.

$$PPR = ((1 - \frac{|Peak\ Load\ of\ Transformer - Provided\ Flexibility\ Amount|}{Peak\ Load\ of\ Transformer}) \times 100) \quad (4)$$

- **Battery energy usage during DC fast charger smart charging sessions (BAT-E) (kWh)**: This KPI is designed to indicate the proportion of power drawn from the battery storage system during the charging process of electric vehicles. It provides information on how much of the required power is sourced from the battery storage system.

- **Grid energy usage during DC fast charger smart charging sessions (GR-E) (kWh) :** This KPI is designed to indicate the proportion of power drawn from the grid during the charging process of electric vehicles. It provides information on how much of the required power is sourced from the grid.

ii. Economical Evaluation

In the economic evaluation section, a fundamental assessment has been conducted to determine the revenue that can be achieved through the flexibility delivery processes carried out during the OEDAS demo studies. The purpose is to evaluate the potential benefits that can be obtained from these flexibility delivery processes.

In this context, when evaluating the process from the perspective of the FSP (Flexibility Service Provider), operational costs, potential incentives that may be applied to encourage end-users, and the penalty component for incomplete delivery have been considered as the basis for determining the potential gains in the flexibility process. These factors are taken into account to determine the potential financial benefits that can be obtained through the flexibility process.

- **Cost**

The flexibility cost for the FSP (Flexibility Service Provider) during the flexibility process has been calculated primarily as follows:

$$Cost = \left(Electricity\ Price_{Buy} - Electricity\ Price_{Sell}\right) \times Flexibility\ Amount_{\text{energy}} \qquad (5)$$

- **Incentivization**

In addition, depending on the test case (in the absence of dynamic pricing), incentives such as discounts or monetary rewards can be offered to encourage end-users to participate in the Demand Response (DR) event. This can result in a decrease in the total cost for the FSP. However, it should be noted that no specific study has been conducted regarding incentivization within the scope of the project.

- **Penalty**

During the flexibility trading between the DSO and FSP, if the flexibility delivery rate falls outside a certain range, penalties may be applied to the FSP. This process directly affects the FSP's flexibility revenue. Taking into account possible measurement errors in the assets and analyzers used in the demo, it has been decided that this range should be %90<x<%110 for the Turkish demo. In other words, if the delivery rate at the end of the flexibility trading process falls outside this range, a penalty may be applied to the FSP at a certain percentage. This penalty is determined by multiplying the deviation percentage of the supplied flexible energy from the planned offer by the supplied offer.

- **Revenue**

At the end of the process, revenue calculation for the flexibility process can be done based on the parameters described above. Simply put, this calculation can be obtained by subtracting any possible penalty fees from the potential gain derived from the price difference in dynamic pricing. This calculated revenue value, in a way, expresses the net profit obtained from the process. The relevant revenue calculation can also include any incentives provided to the FSP if applicable.

$$Revenue_{\ FSP} = (Cost - Penalty) + (Incentive)_{FSP} \qquad (6)$$

iii. **Environmental Evaluation**

During the evaluation studies, a simple analysis has been conducted to determine the extent of carbon emission reduction achieved through smart charging processes involving electric vehicles (EVs) and, indirectly, PV panels. Within this scope, the impact of electric vehicle charging processes on carbon emission reduction has been measured based on certain assumptions. As an example, the following calculation methodology provides information about the calculation of the avoided CO2 amount obtained from one vehicle. This calculation for one vehicle serves as the basis for calculating the avoided CO2 amount achieved through electric vehicle charging sessions run through the EV management platform and is calculated in parallel with the charging processes conducted for the entire system. It should be noted that different assumptions may yield different results. The fundamental assumptions made are as follows:

- It is assumed that electric vehicles (specifically the Nissan LEAF) consume approximately 16.5 kWh of energy per 100 km and travel approximately 16,000 km per year.
- The value for the Turkish electricity mix is assumed to be 0.41 kg CO2/kWh.
- Based on real-time monitored PV production data, it is assumed that 10% of the EV charging sessions conducted during the OEDAS demo are powered by green energy.
- The CO2 emission value for green energy is taken as 0.055 kg CO2/year.
- For comparison, an ICE vehicle that travels 12,000 km per year and consumes an average of 6.5 liters of petrol per 100 km is considered.

The calculation for one e-vehicle can be seen in Table 1

Table 1 Avoided CO2 value calculation for charging of one EV in Turkish pilot

Parameter	Value	Unit	Assumption	Source
Number of Vehicle	1	-		
TR Electricity mix	0.41	kg CO2/kWh		https://app.electricitymaps.com
Average km/year	12000	km		
Consumption per 100 km	16.5	kwh		
Annual consumption	1980	kwh		
Potential energy losses	17%	-		
Total consumption with losses	2316.6	kwh		
Green Energy CO2 emission	0.055	kg CO2/kWh	55 gr CO2 emission per kwh for solar	https://www.nexxtlab.lu/co2-emissions-calculator/
Green Energy usage during charging	10%	-		
Amount of CO2 emission for charging from green energy	12.741	kg CO2/year		https://www.nexxtlab.lu/co2-emissions-calculator/
Amount of CO2 emission for charging from grid	854.8	kg CO2/year		
Total EV charging emissions	867.6	kg CO2/year		
ICE emission/year	2200	kg CO2/year	Average 12.000 km, 6.5 lt petrol consumption per 100 km	https://www.nexxtlab.lu/co2-emissions-calculator/
Avoided CO2/yıl	1332	kg CO2/year		
No.of Tree that provides same amount of CO2	95	-		
Avoided CO2 Rate	60.57%	%		

As a result, these KPIs have been determined for the evaluation process, and different KPIs have been calculated for different assets. Table 2 provides an overview of which KPIs will be evaluated for which test case and asset.

Table 2 KPI list for each asset and test case

Technical Evaluation		
KPI	Test Case	Asset
FDR	TC 8.9 TC 8.10 TC 8.12	V2G charger DC charger Battery storage
FAI	TC 8.9 TC 8.10 TC 8.12	V2G charger DC charger Battery storage
PPR	TC 8.9 TC 8.10 TC 8.12	V2G charger DC charger Battery storage
BDF	TC 8.12	Battery storage
BAT-E	TC 8.12	Whole system
GR-E	TC 8.12	Whole system
Economical Evaluation		
KPI	Test Case	Asset
Net Revenue	TC 8.9 TC 8.10	V2G charger Battery storage
Environmental Evaluation		
KPI	Test Case	Asset
Avoided CO2 Rate	TC 8.12	Whole system

2.1.2 Flexibility Test-Cases Evaluation

2.1.2.1 TC 8.9 Provision of flexibility by Battery Storage System and V1G compatible DC charger

The scope of the relevant test case involves separate smart charging processes carried out with the battery storage system and the DC EV charger. Through the EV management platform, the respective processes were evaluated, and the KPIs were assessed on an equipment basis.

i. Battery storage system

- **Test case description:**

Two separate tests were conducted using a Battery Storage System. The main objective of the first test was to reduce the transformer load value (with the load-based balancing as described in D8.3), based on the load threshold level determined by the DSO. In addition, in a different scenario, the process was evaluated from the perspective of the FSP. In this case, a demo was conducted based on price-based optimization, aiming for the FSP to benefit from fluctuations in spot market prices and generate profit.

Load-based optimization:

In the test conducted within the scope of load-based optimization, the charging and discharging of the battery were carried out between 07:15 am in the morning and 14:30 pm in the afternoon, based on the transformer load threshold determined by the DSO. Accordingly, the calculated setpoints for the battery can be seen in Table 3.

Table 3: Calculated setpoints for batteries during smart charging.

Time	Transformer Load Value (kW)	Threshold	Battery Setpoints	Battery Charging/Discharging Power(Avrg - kW)	Final Transformer Value (kW)
10:15-10:30	130.5	120	-10	-9.91	120.5
10:30-10:45	125.4		-5.5	-5.5	119.9
10:45-11:00	110.25		9.75	9.65	120
11:00-11:15	142	152	10	9.94	152
11:15-11:30	145.8		6.2	6.15	152
11:30-11:45	143.2		8.8	8.76	152
11:45-12:00	162.35		-10	-9.98	152.35
12:00-12:15	182.5	165	-10	-9.96	172.5
12:15-12:30	148.29		10	9.97	158.29
12:30-12:45	160.3		4.7	4.66	165
12:45-13:00	170.3		-5.3	-5.27	165
13:00-13:15	174.8		-9.8	-9.78	165
13:15-13:30	178.45		-10	-9.99	168.45
13:30-13:45	165		0	0	165
13:45-14:00	168.8		-3.8	-3.76	165
14:00-14:15	178.95	170	-9	-8.98	169.95
14:15-14:30	165.2		5	4.97	170.2
14:30-14:45	162.9		7	6.98	169.9
14:45-15:00	165.8		4.2	4.08	170
15:00-15:15	174.4	155	-10	-10.02	164.4
15:15-15:30	138.65		10	9.96	148.65
15:30-15:45	157.47		-2.5	-2.48	154.97
15:45-16:00	145.21		9.8	9.76	155.01
16:00-16:15	170.1	175	5	4.96	175.1
16:15-16:30	165.56		9.4	9.37	174.96
16:30-16:45	179.82		-5	-4.98	174.82
16:45-17:00	170.65		4.5	4.44	175.09

As seen in the table, the battery performs charging and discharging operations at different times. Charging is done when the threshold level set by the DSO is relatively low, while discharging is done when the threshold level is high. This provides flexibility to the system during discharge moments. KPIs considered and calculated throughout the session in accordance with the test case can be seen in Table 4.

Table 4: Calculated KPIs for load based optimization of battery

Test Case	Technical KPIs		
	FDR (%)	FAI (%)	PPR (%)
Load based optimization with battery - discharging	99.52	100	5.60
Load based optimization with battery - charging	99.24	100	-

In the above case, as part of the load balancing profiling study conducted through the battery storage system, KPIs have been calculated, and information has been provided regarding the system's performance for a single case. Additionally, an evaluation was carried out over a longer period of approximately 30 days using a stationary battery storage system. During this evaluation, daily peak moments were determined based on the transformer load profiles for 30 days. Setpoints were then sent to automatically utilize the battery storage system's discharge function at those moments. As a result, the battery storage system provided support to the system's load.

The calculated KPIs based on the study conducted are presented in Figure 1.

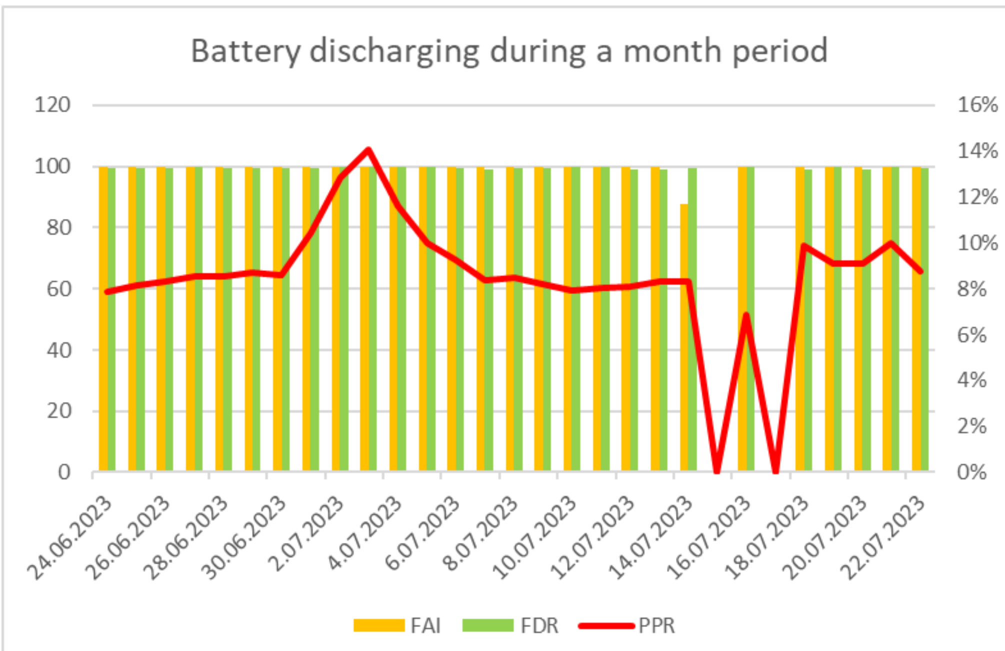

Figure 1 KPI calculation of battery during one month period

According to Figure 1, it is evident that the battery storage system contributed between 8% and 15% towards reducing the daily peak load throughout the one-month period, utilizing its maximum discharge capacity. Additionally, for most of the 30 days, the FAI and FDR values remained close to 100%. This suggests that the battery was consistently ready for service and responded to the given setpoints at nearly 100% efficiency. However, on the specific dates of July 15th and July 17th, 2023, the battery storage system encountered a technical issue in its management system, resulting in the batteries failing to respond to the designated setpoints. As a consequence, the discharge could not be fully carried out on those days, leading to FAI and FDR values of 0 for those particular days.

If we disregard the technical issue, it can be concluded that the battery storage system operated efficiently throughout the process, adhering to the specified setpoints and providing contributions to reducing the peak load according to its capacity.

Price based optimization:

The relevant test case aimed to demonstrate the profit obtained by the FSP who owns the battery storage system by exploiting the hourly variations in market prices. Within the test case, considering the hourly spot market pricing, the FSP determined a base price, and a demo was conducted based on 1) charging the battery storage system when the actual market price is below this base price and 2) discharging it when it is above. Charging was performed at half power, while discharging was done at full power to maximize the profit. The determined setpoints and market price information resulting from the conducted study are presented in Table 5.

Table 5: Calculated setpoints and market price information

Time	Average Charging&Discharging Power (kW)	SoC (%)	Market Price (TL/kWh)
10:30:00	-9.89	71.14	3.65
11:00:00	-9.92	56.11	3.28
12:00:00	4.91	27.00	2.71
13:00:00	4.94	41.50	2.71
14:00:00	4.94	56.20	2.73
15:00:00	4.94	71.00	2.95
16:00:00	4.94	85.50	2.25
17:00:00	-9.96	97.10	3.20
18:00:00	-9.84	67.62	3.65
19:00:00	-9.93	36.50	3.55
20:00:00	-0.01	22.00	3.55
21:00:00	0.01	22.00	3.54
22:00:00	4.93	23.00	2.87
23:00:00	4.93	47.33	2.80
00:00:00	4.95	61.52	2.80

Since the process is evaluated from the FSP perspective, the focus is on economic KPIs (specifically the revenue the FSP will generate) compared to technical KPIs. The economic KPIs calculated according to the methodology presented in the first section are presented in Table 6.

Table 6: Calculated economical KPIs for price based optimization of battery

Test Case	Economical KPIs						
	Avrg. Elec. Price (Buy)	Avrg. Elec. Price (Sell)	Total Amount of Energy	FAI (%)	Cost (TL/kWh)	Penalty (TL/kWh)	Revenue (TL/kWh)
Price based - charging	2.72	-	19.74	100	53.8404	0	-53.8404
Price based - discharging	-	3.46	24.77	100	85.8378	0	85.8378
Total							**31.9974**

ii. DC electric vehicle:

Test case description:

Within the test case, the aim was to provide flexibility to the grid by managing an unidirectional high-speed electric vehicle charging station through smart charging algorithm. Due to the fact that a one-way DC charging station does not allow energy transfer to the grid, flexibility potential can only be achieved by shifting the load or reducing consumption at certain times. In this context, an optimization example was carried out with a one-way 50 kW fast DC charging station, where a potential user and DSO were included in the scenario. The main objective was to determine the charging profile based on the threshold value set by the distribution company at any given time of day, in such a way that the transformer consumption threshold established by the distribution company would not be exceeded during electric vehicle charging, whether during peak or non-peak hours.

As a result of the test conducted between 15:45 and 16:45, the "power" setpoints determined by the intelligent charging algorithm (based on the requirements of the DSO and end-users) are presented in Table 7.

Table 7: Calculated smart charging values for DC charger

Time	Transformer Base Load Value (kW)	Transformer Load Threshold (kW)	DC Charger Setpoints	Final Transformer Load Value (kW)
15:45-16:00	95.56	145	46.00	141.56
16:00-16:15	133.08	145	11.90	144.98
16:15-16:30	129.91	145	15.20	145.11
16:30-16:45	124.55	145	20.50	145.05

To demonstrate the provided flexibility, the smart charging session was compared to a scenario where the electric vehicle was charged without the use of smart charging. The impact of smart charging on the transformer load is shown in Figure 2.

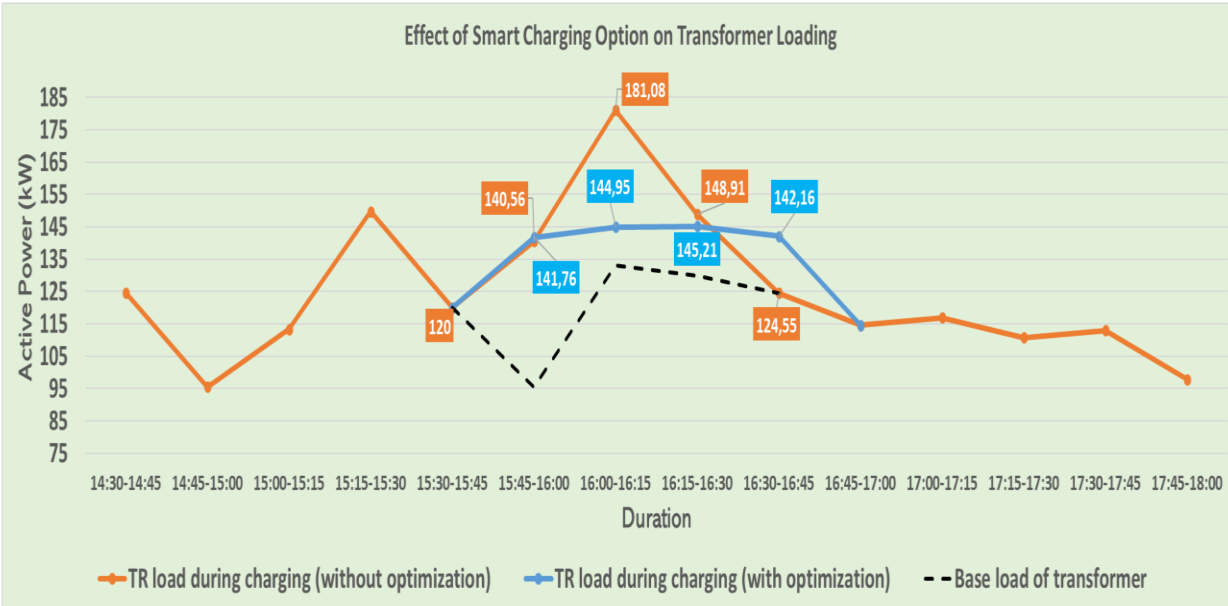

Figure 2 Flexibility potential of smart charging option (with DC charger) on transformer loading

Particularly in the last 15 minutes of the smart charging process, it can be observed that the charging process was not carried out at the exact specified charging power. Here, a charging command of 20.5 kW was sent, but the actual charging power started at 20.5 kW and decreased to around 14 kW, resulting in an average of 17 kW. The main reason for this is that the vehicle's own BMS limits the charging current for a healthy charging process, especially after the battery SoC reaches 80%. Table 8 is showing the values.

Table 8: Calculated-Actual Charging powers during smart charging and standard charging

Time	Smart Charging		Standart Charging	
	Smart Charging Command (kW)	Actual Power (Average -kW)	Charging Command (kW)	Actual Power (Average -kW)
15:45-16:00	46	46.2	-	45.2
16:00-16:15	11.9	11.87	-	48.1
16:15-16:30	15.2	15.3	-	20.9
16:30-16:45	20.5	17.61	-	-

In line with this, the KPIs considered for the conducted study have been calculated as shown in Table 9.

Table 9: Calculated KPIs for DC fast charger

Test Case	Charging Time	Technical KPIs		
		FDR (%)	FAI (%)	PPR (%)
Smart charging with DC fast charger	15:45-16:00	100.05	100%	-
	16:00-16:15	99.97	100%	19.95
	16:15-16:30	100.02	100%	-
	16:30-16:45	88.12	100%	-

In addition to the study presented above, which includes the details and main perspective with KPIs, a separate study was conducted covering a period of 2.5 months, specifically in May and July. During this 2.5-month period, 30 smart charging sessions were carried out with a DC electric vehicle. These sessions were generally performed spontaneously based on the charging needs of the OEDAS personnel using the vehicle. The data obtained during this 2.5-month period was used to calculate KPIs, and the results are depicted in Figure 3.

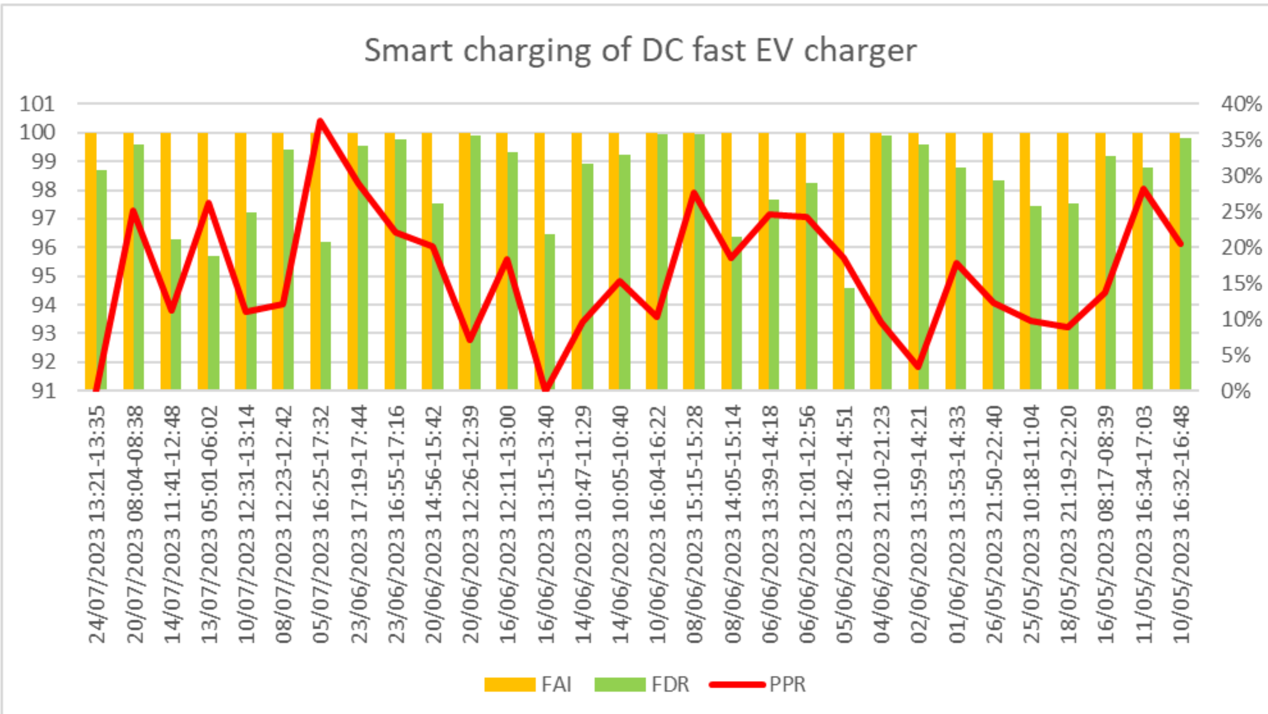

Figure 3 KPI calculation of DC charger after long term tests

As seen in Figure 3, the DC charging station provided uninterrupted service with an FAI value close to 100% for almost the entire test period. However, it is evident that the FDR value is lower compared to the battery storage system. The primary reason for this is that the charging power of the vehicle is determined independently by the vehicle's internal BMS, regardless of the setpoint values sent to the vehicle, especially after reaching around 75-80% SoC.

As a result, discrepancies arose between the sent and actual charging powers during charging sessions where the user wanted to take the vehicle with a SoC above 75-80%. If this aspect is not taken into account, FDR values close to 99% can be observed for charging sessions that terminate before reaching 75-80% SoC.

Additionally, the DC charging station prevented the occurrence of possible peak loads during the day compared to the standard charging process. It can be observed that, in this context, potential peak loads can be reduced by 8% to 35% compared to the peak demand that would occur during a standard charging process.

Discussion

During the conducted studies, it has been observed that both the battery storage system and the fast electric vehicle charging station were able to perform charging and discharging operations smoothly and in accordance with the setpoints determined by the smart charging algorithm.

The demonstration showed that the battery storage system can be dynamically utilized to prevent possible congestion in the transformer load for the DSO. During the studies, although not measured quantitatively, it was observed that the batteries responded very quickly to the setpoints and could reach the desired power value from standby mode within 1-2 seconds during charging and discharging. While there are battery models that provide even faster responses in the market, the response time achieved in this case is sufficient for the intended purpose of providing load support to the transformer. Furthermore, it was observed that the availability rate of the batteries while in service was 100%, and they responded seamlessly to the respective setpoints. Additionally, the slight deviation in the FDR value of the battery is believed to be related to the output power that each parallel battery pack can provide. When examining certain setpoints, fractional values are observed, and the output power of the battery packs may be slightly above or below this value. Therefore, the small deviation is considered acceptable.

From the perspective of the FSP, the performance of the battery storage system can be evaluated in terms of financial gains. The FSP, as the owner of the battery, can discharge the battery during peak times (when energy prices are high) and charge it during off-peak times (when energy prices are relatively cheaper) to achieve monetary benefits. In the study, since there is no real market mechanism or pricing system available for the Turkish case, the spot market day-ahead prices in the Turkish electricity market were used. In a very basic sense, it was demonstrated that the FSP can benefit from this arbitrage opportunity and generate profits.

In the fast electric vehicle charging station, it was also observed that the electric vehicle charging station responded very quickly to the sent setpoints. However, there is a higher deviation in the FDR value compared to stationary battery storage. This is primarily because the vehicle itself has an internal battery management system, which handles power distribution after a certain SoC value for a healthy charging process. Especially after reaching around 80% SoC, the charging power is reduced and the charging process slows down due to the battery's chemistry and heat dissipation. As a result, there is a difference between the charging power value realized and the setpoint calculated by the smart charging algorithm, which has led to a decrease in the FDR value. Looking at the FAI, the charging station remained available (100%) throughout the session and dynamically communicated the calculated setpoints to the vehicle.

As mentioned, the flexibility provided by the high-speed electric vehicle charging station is aimed at reducing the high demand in consumption by mitigating peaks during charging. As evident from the PPR value, in the example session conducted, the peak load in the transformer could be reduced by approximately 20%. This situation demonstrates the impact of DSO coordinated smart charging operations, especially during peak times, in preventing grid congestion issues.

2.1.2.2 TC 8.10 Provision of flexibility by EV-V2G platform

During the tests conducted with the V2G charging station, the specified KPIs were calculated based on the performed sample test cases. The test cases carried out with the V2G charger encompass load-based and price-based optimizations, similar to the battery storage system. The details are presented in the following sections.

Load based optimization with V2G charger:

The primary scenario here involves calculating the charge/discharge or consumption interruption signals for the V2G vehicle based on the charging requirements provided by the electric vehicle user and the consumption threshold determined by the DSO for the transformer connected to the charger. These calculated setpoints were communicated to the electric vehicle charging station through Open charge point protocol (OCPP), and the charging/discharging process was carried out by the vehicle. The table containing the calculated and average charge/discharge power values can be seen in Table 10.

Table 10: Calculated setpoints for V2G charger during smart charging

Slots	Time	Transformer Load Value (kW)	Load Threshold	V2G Charger Setpoints	V2G Vehicle SoC (%)	V2G Charging Discharging Power (Avrg - kW)	Final Transformer Value (kW)
Charging	11:45-12:00	165.49	175	9.50	50-55	9.60	175.09
Pause	12:00-12:15	174.39	175	0.00	55	0.00	174.39
Charging	12:15-12:30	161.55	175	10.00	55-59	9.90	171.45
Pause	12:30-12:45	178.76	175	0.00	59	0.00	178.76
Charging	12:45-13:00	165.36	175	10.00	59-64	9.90	175.36
Pause	13:00-13:15	174.41	175	0.00	64.00	0.00	174.41
Charging	13:15-13:30	168.14	175	6.50	64-67	6.70	174.84
Pause	13:30-13:45	180.83	175	0.00	67	0.00	180.83
Charging	13:45-14:00	168.41	175	6.50	67-71	6.80	175.21
Charging	14:00-14:15	166.91	175	8.00	71-75	8.00	174.91
DR	14:15-14:30	160.4	175	0.00	75	0.00	160.40
Discharging	14:30-14:45	178.76	150	-10.00	75-70	-9.92	188.68
Discharging	14:45-15:00	160.83	150	-10.00	70-65	-10.05	150.83
Discharging	15:00-15:15	154.4	150	-4.45	65-63	4.37	149.95
Discharging	15:15-15:30	155.03	150	-5.10	63-60	-5.10	149.93
Discharging	15:30-15:45	158.45	150	-8.50	60-57	-6.71	151.74
Pause	15:45-16:00	151.21	150	0.00	57.00	0.00	151.21
Charging	16:00-16:15	140.56	150	9.60	57-62	9.55	150.16
Charging	16:15-16:30	142.11	150	7.50	62-65	7.46	149.61
Charging	16:30-16:45	140.56	150	10.00	65-70	9.60	150.16
Charging	16:45-17:00	136.45	150	10.00	70-75	10.09	146.54

For the V2G charger, the following KPIs presented in Table 11 have been considered.

Table 11: Calculated setpoints for V2G charger during smart charging

Test Case	Technical KPIs		
	FDR (%)	FAI (%)	PPR (%)
Load based opt. with V2G charger - charging	99.7	100%	-

Load based opt. with V2G charger - discharging	96.2	93.78%	5.26

Price based optimization with V2G charger:

In this scenario, the main premise is that a potential user of a V2G (Vehicle-to-Grid) compatible electric vehicle would be encouraged to charge their vehicle during periods when electricity prices are low, as determined by the DSO's pricing structure. Conversely, the user would be prompted to discharge their vehicle back to the grid during periods of high electricity prices. This scenario is designed to encourage V2G users to consume electricity during off-peak hours and to help balance the grid by supplying power during peak hours.

According to the scenario, the DSO first develops a load-based electricity pricing scheme based on the current transformer load and hourly load estimates. Defined tariff structure can be seen in Table 12.

Table 12: DSO's tariff structure for demo study

Transformer Load Value (kW)	Transformer Loading (%)	Price (TL/kWh)
>180	>%90	3.8
180-160	%90-%80	3.5
160-140	%80-%70	2.9
140-120	%70-%60	2.5
<120	<%60	2.1

Based on the defined tariff structure, charge and discharge operations have been conducted, aiming for the electric vehicle user to benefit from the process. A base price of 2.65 TL/kWh has been considered for this purpose, and setpoints have been determined accordingly. The basic process is automated as follows: If the price set by the DSO is below the base price, the vehicle is charged at full power; otherwise, it is discharged at full power. The setpoints determined in accordance with this approach are presented in Table 13.

Table 13: Calculated charge/discharge profiles and market prices for the study

Time	Transformer Load Value (kW)	Market Price	V2G Charger Setpoints	V2G Vehicle SoC (%)	V2G Charging Discharging Power (Avrg - kW)	Final Transformer Value (kW)
09:45-10:00	161.22	3.5	-10.00	72-67	-10.01	151.21
10:00-10:15	183.32	3.8	-10.00	67-62	-9.99	173.33
10:15-10:30	167.39	3.5	-10.00	62-57	-9.99	157.40
10:30-10:45	171.31	3.5	-10.00	57-54	-9.97	161.34
10:45-11:00	166.46	3.5	-10.00	54-49	-10.02	156.44
11:00-11:15	181.99	3.8	-10.00	49-44	-9.98	172.01
11:15-11:30	166	3.5	-10.00	44-39	-9.99	156.01
11:30-11:45	171.72	3.5	-10.00	39-35	-9.96	161.76
11:45-12:00	160.52	3.5	0.00	35	0.00	160.52
12:00-12:15	174.33	3.5	0.00	35	0.00	174.33
12:15-12:30	161.42	3.5	0.00	35	0.00	161.42
12:30-12:45	168.25	3.5	0.00	35	0.00	168.25

12:45-13:00	162.68	3.5	0.00	35	0.00	162.68
13:00-13:15	175.44	3.5	0.00	35	0.00	175.44
13:15-13:30	167.62	3.5	0.00	35	0.00	167.62
13:30-13:45	162.56	3.5	0.00	35	0.00	162.56
13:45-14:00	168.21	3.5	0.00	35	0.00	168.21
14:00-14:15	169.48	3.5	0.00	35	0.00	169.48
14:15-14:30	161.41	3.5	0.00	35	0.00	161.41
14:30-14:45	164.9	3.5	0.00	35	0.00	164.90
14:45-15:00	158.6	2.9	0.00	35	0.00	158.60
15:00-15:15	153.96	2.9	0.00	35	0.00	153.96
15:15-15:30	155.12	2.9	0.00	35	0.00	155.12
15:30-15:45	155.17	2.9	0.00	35	0.00	155.17
15:45-16:00	149.33	2.9	0.00	35	0.00	149.33
16:00-16:15	156.41	2.9	0.00	35	0.00	156.41
16:15-16:30	142.07	2.9	0.00	35	0.00	142.07
16:30-16:45	136.55	2.5	0.00	35	0.00	136.55
16:45-17:00	137.67	2.5	0.00	35	0.00	137.67
17:00-17:15	107.17	2.1	10.00	35-40	10.04	97.13
17:15-17:30	135.66	2.5	10.00	40-45	9.98	125.68
17:30-17:45	117.52	2.1	10.00	45-50	9.97	107.55
17:45-18:00	133.96	2.5	10.00	50-55	9.96	124.00
18:00-18:15	119.59	2.1	10.00	55-59	10.12	109.47
18:15-18:30	135.03	2.5	10.00	59-64	10.03	125.00
18:30-18:45	126.62	2.5	10.00	64-68	9.98	116.64
18:45-19:00	136.95	2.5	10.00	68-73	9.98	126.97
19:00-19:15	126.21	2.5	10.00	75	10.02	116.19

As can be seen from Table 13, the charge/discharge profiling and execution have been demonstrated smoothly based on the condition of the base price. In the scope of the test case, the following KPIs have been considered to demonstrate the potential revenue for an FSP and have been calculated specifically for the test case.

Table 14: Revenue calculation of FSP during V2G charging/discharging session

Test Case	Economical KPIs						
	Avrg. Elec. Price (Buy)	Avrg. Elec. Price (Sell)	Total Amount of Energy	FAI (%)	Cost (TL/kWh)	Penalty (TL/kWh)	Revenue (TL/kWh)
V2G Price based - charging	2.36	-	22.52	100	53.2827	0	-53.2827
V2G Price based - discharging	-	3.55	19.97	100	70.9125	0	70.8935
		Total					**17.6108**

Discussion

The conducted studies have demonstrated that the smart charging process can be implemented with real assets and systems, based on the preferences of V2G vehicle users and the DSO's load threshold value.

The coordinated management of V2G-enabled vehicles with end-users has been shown to benefit in preventing grid constraints for DSOs. The V2G-enabled vehicle batteries, acting as mobile flexibility sources, hold significant potential for flexibility from the perspective of DSOs.

It has been observed that the V2G vehicle charging station responds very quickly to the variable setpoints communicated through OCPP. Therefore, being able to rapidly respond to flexibility requests and being controlled accordingly provides advantages for DSOs. During the load based optimization test case, there is no significant deviation in the FAI value during charging, and the V2G vehicle has dynamically responded to the corresponding demand throughout the session. Additionally, there is a very slight deviation in the FDR value of the battery. This could be attributed to the behavior of the vehicle battery's internal BMS. But during the discharging as can be seen in Table 11, FAI rate is lower than expected. The reason for this situation is that during discharging, the V2G charger spontaneously terminates the session for a moment and resets itself. This causes the asset to be out of service for 5-5.5 minutes until it resumes discharging. Therefore, as can also be seen from the FDR value, the desired average flexibility value requested at that particular moment could not be fully achieved. The reason why the charging station resets itself is not understood.

When evaluating the performance of the V2G vehicle battery from an FSP perspective, the vehicle owner can benefit financially by discharging the battery during peak hours (when energy prices are high) and charging it during off-peak hours (when energy prices are relatively lower). A dynamic tariff structure defined by the DSO can encourage EV users to engage in this behavior. As can be seen from the Table 14, V2G EV user made profit with charging and discharging of the car battery evaluated with the electricity price differences that was provided by DSO. Alternatively, during flexibility events, the DSO can send demand response signals to EV users, to request flexibility. This scenario has been tested in the conducted studies, and it has been observed that the vehicle can dynamically respond to the "direct flexibility" request sent by the DSO. Additional incentives can be applied to involve the user in this process. However, the specific demo did not focus on implementing such incentivization processes.

2.1.2.3 TC 8.12 Provision of flexibility services with the whole system

During the evaluation process, multiple charge/discharge sessions were conducted using two electric vehicles and a battery storage system in the demo studies. In this section, calculations were performed based on the presented KPIs to assess the overall impact created by the entire system over the designated period.

During the designated period, simultaneous discharge operations were performed either through smart charging concepts or flexibility requests from the DSO. The objective was to achieve reductions in the instantaneous peaks of the transformer load profile throughout the day. Given that the discharge powers of the assets involved in the study (10 kW for both the battery and V2G) were relatively small, their impact on the total load of the transformer was not huge. However, the tests conducted have demonstrated the feasibility of their use in the system, so it can be said that more remarkable results could be achieved when applying this solution with a larger number of electric vehicles in a larger geographical area.

Evaluation of V2G charger and stationary battery together:

As part of this test, a V2G charger and battery storage system were operated for approximately 22 hours to observe their impact on the grid load for the purpose of load balancing. During the test, the battery and electric vehicle were intended to provide services to the grid without exceeding the load threshold set by the DSO for one day. In the scenario, it was assumed that the electric vehicle remained connected to the charger and was not used by the user throughout the day. The initial SoC for the vehicle is 88%, and the desired SoC level when the user retrieves the vehicle is also set to 88%. Similarly, within the battery storage system, the initial SoC is 100%, and after one day, the battery owner is expected to receive the battery with 100% SoC.

In the scenario, different load thresholds for specific parts of the day were entered into the IoT platform's EV management dashboard by the DSO. The smart charging algorithm used this input to calculate the charge/discharge profiles to balance the transformer load. The visual representation of the transformer load before and after optimization can be seen in Figure 4 as a result of the conducted study.

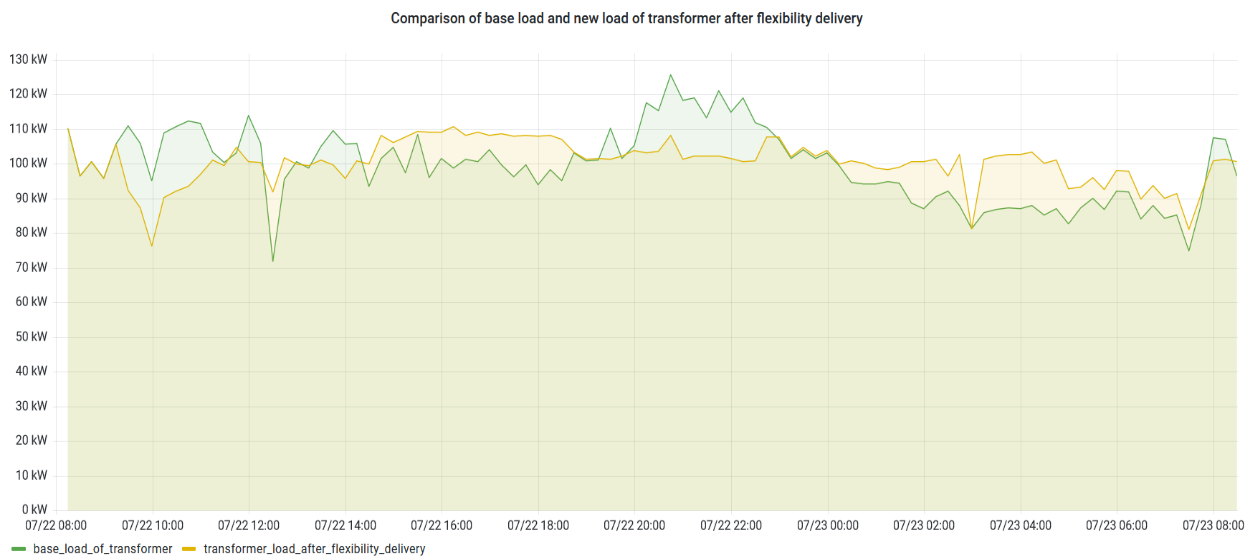

Figure 4 Visualization of transformer load in FlexiGrid IoT platform after smart charging process

As evident from Figure 4, the green line represents the base load of the transformer, while the orange line indicates the actual load of the transformer after the charging or discharging process. As can be seen, the smart charging algorithm has limited the daily peaks based on the preferences of both the DSO and the users, approximately during a 23-hour period. During these times, setpoints for discharging the system were sent. On the other hand, the charging process was scheduled for relatively lower-demand periods during the day or after midnight. This approach resulted in a more consistent load profile throughout the day, rather than having fluctuating peaks.

At the end of the one-day process, both the electric vehicle and the battery storage system were presented to the users with their initial SoC values (88% and 100%, respectively). Throughout the process, visual data from the IoT platform regarding the charging and discharging operations in the V2G charging station and battery storage system is provided in Figure 5 and Figure 6.

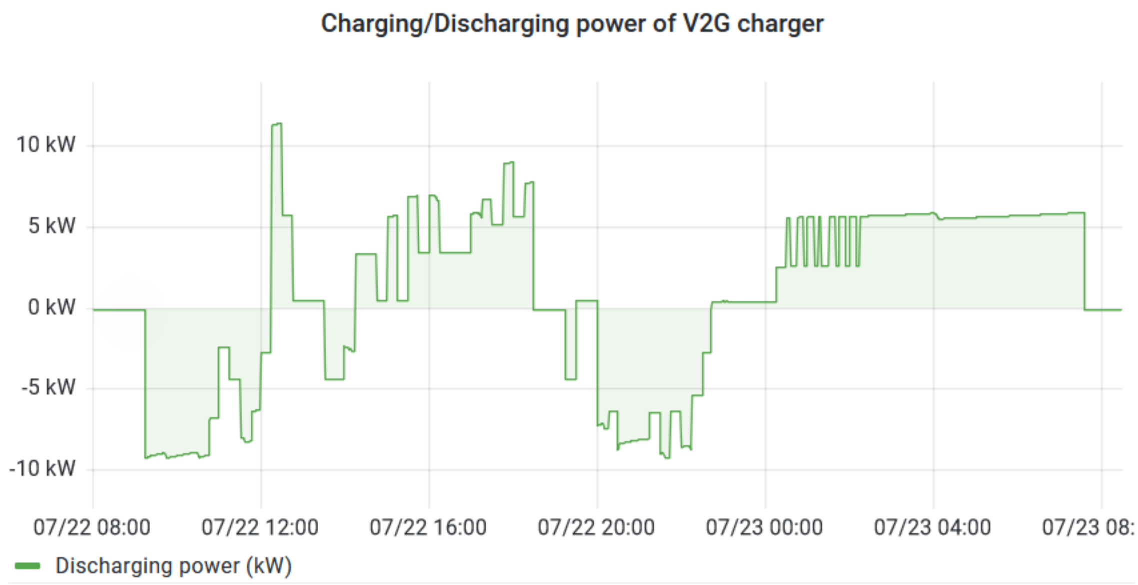

Figure 5 Charge/discharge profile of V2G charger

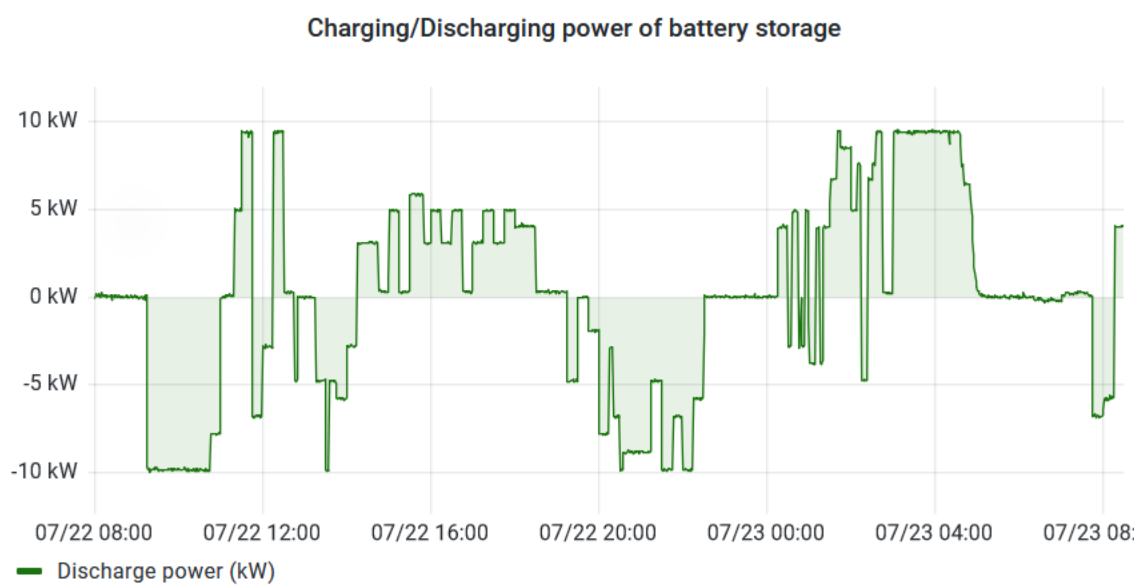

Figure 6 Charge/discharge profile of stationary battery

Throughout the study, the profiling and charging-discharging operations were carried out based on the spot market prices integrated into the system. This approach allows both the electric vehicle user and the battery storage system operator to benefit from price variations and potentially earn profits. Although not demonstrated in this case, the DSO could offer possible incentives to encourage end-user participation, which would create additional gains for the end-users.

During the time intervals of the study, the day-ahead market prices in the Turkish electricity spot market can be observed in Figure 7.

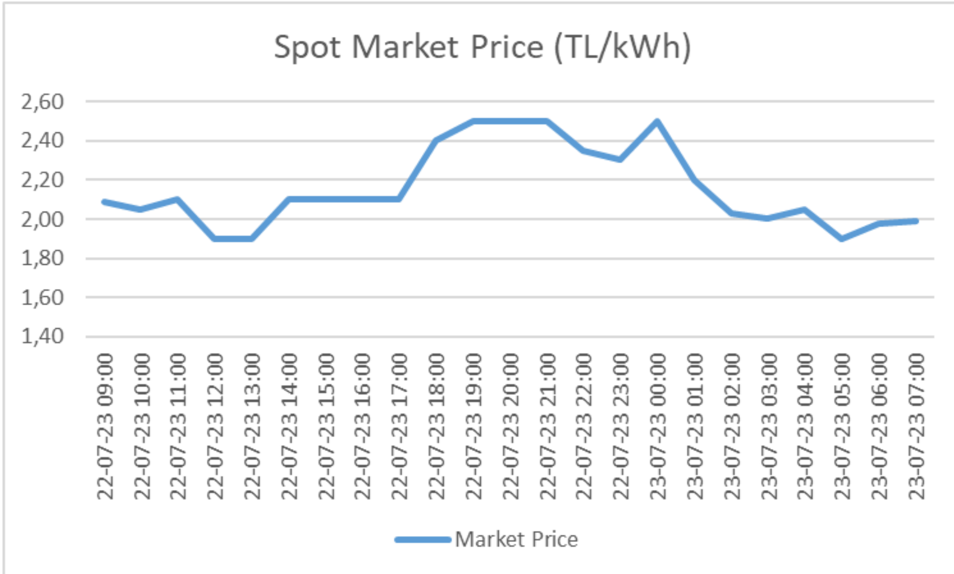

Figure 7 Day ahead electricity prices in Turkish electricity spot market

Table 15: Technical KPI calculation for the study

Test Case	Technical KPIs		
	FDR (%)	FAI (%)	PPR (%)
Load based optimization with battery and V2G vehicle	99.41	100	15.91

Table 16: Economical KPI calculation for the study

Test Case	Economical KPIs							
	Avrg. Elec. Price (Buy)	Avrg. Elec. Price (Sell)	Total Amount of Energy (Buy)	Total Amount of Energy (Sell)	FAI (%)	Cost (TL/kWh)	Penalty (TL/kWh)	Revenue (TL/kWh)
Load based optimization with battery	2.08	2.23	44.25	52.5	100	92.01	0	19.93
Load based optimization V2G vehicle	2.06	2.24	53.5	52.25	100	111.67	0	4.56
Total								**24.4912**

As can be seen from Table 16, despite the primary goal of load balancing in the study, the users who own both the battery and the electric vehicle have managed to profit from changes in spot market pricing. The differences in profit amounts are attributed to the variation in setpoints determined during the load balancing process. In this case, the battery owners have earned more profit because they charged the battery with higher power during the cheaper time periods.

It's worth noting that the ability to adapt charging and discharging patterns based on spot market prices provides an advantage for the users to optimize their gains while still contributing to the overall load balancing objective. This highlights the potential benefits of incorporating real-time pricing information into the smart charging algorithm for both individual users and the overall grid system.

Long term evaluation of battery storage system

In addition to the previous study, an evaluation was conducted with a stationary battery storage system covering a longer period of approximately 30 days. During this period, the battery storage system was discharged during the day at peak moments when the transformer load was high. On the other hand, during relatively less loaded periods, the battery system was charged.

The load profile of the existing transformer varies depending on the characteristics of the load it serves, showing differences based on seasonal variations and weekdays/weekends. When examining the load profile, it is observed that on weekdays, the transformer experiences peak load during the midday hours, while on weekends, this peak load can extend from midday to the evening hours. The available data indicates that the monthly load profile of the transformer, as shown in Figure 8, demonstrates the peak load during the midday hours when analyzed on a monthly basis.

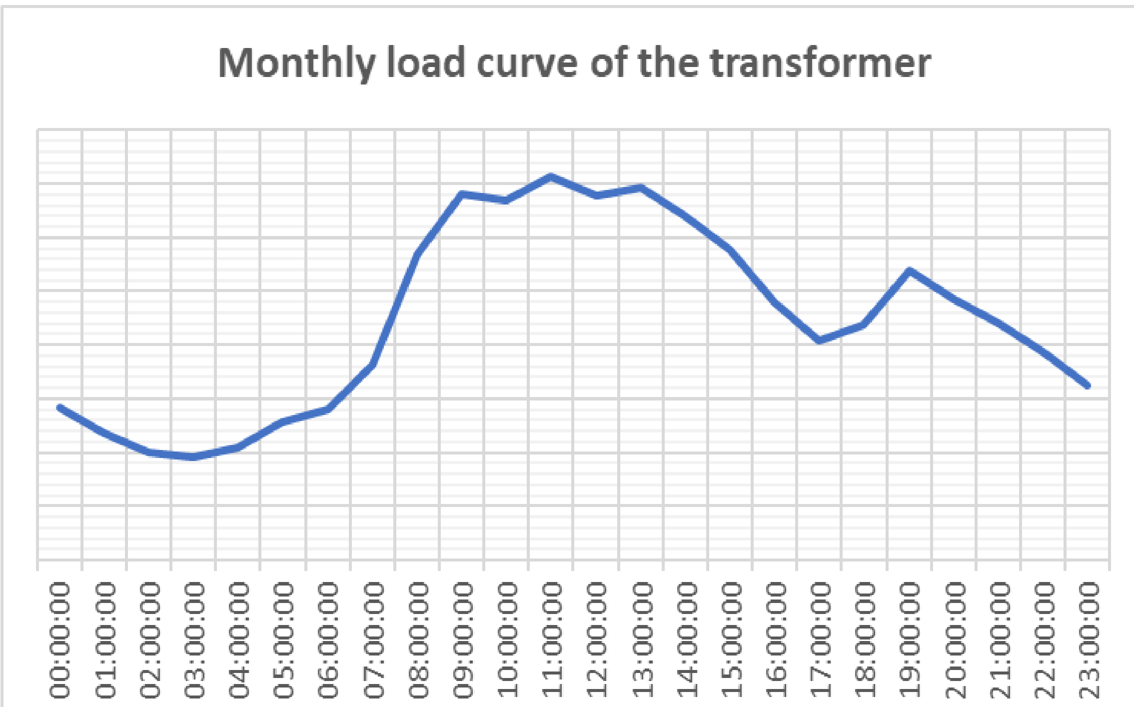

Figure 8 Monthly load profile of local transformer

Based on this information, peak times have been defined for the system using the FlexiGrid IoT platform. The defined peak time intervals sometimes vary depending on the days but mostly cover the morning hours from 09:30 to 12:00 am and the afternoon hours from 13:00 to 14:00 pm. The EV management platform is designed to send maximum power discharge commands to the assets during peak times, leading to a discharge operation of the battery storage system with a power of 10 kW. The specified KPIs have been calculated based on the battery's performance during this period and are presented in Table 17.

Table 17: Technical KPI calculation for the study

Test Case	Technical KPIs		
	FDR (%)	BDF (kWh)	PPR (%)
Long term evaluation of stationary battery storage	99.76	763.27	9.02

Long term evaluation of DC charger with stationary battery storage:

In addition to the V2G charger, a smart charging evaluation has also been conducted for the DC charger. In this context, 30 different smart charging sessions were carried out using the DC charger during the months of June and July. During these sessions, the DSO determined different transformer load threshold levels based on the grid's condition, and the smart charging algorithm performed profiling accordingly.

Throughout the study, the battery storage system also provided load support during the charging process, and discharge profiles for the battery storage system were calculated according to the load status. The specified and calculated KPIs can be observed in Table 18, reflecting the performance of the system during the smart charging sessions conducted with the DC charger.

Table 18: Technical KPI calculation for the study

Test Case	Technical KPIs				
	Number of Charging Sessions	GR-E (kWh)	BAT-E (kWh)	BAT-E (%)	PPR (%)
Long term evaluation of DC charger with stationary battery storage	33	481.62	117.45	24	9.2

Environmental evaluation of the performance of whole system:

Finally, taking into account all the test studies conducted with electric vehicles starting from the beginning of 2023, the environmental KPI has been calculated. Following the parameters and assumptions specified in the 2.1.1 Evaluation Method section, the CO2 reduction value for the EV charging processes has been calculated, as presented in Table 19.

The CO2 reduction value is a crucial metric that quantifies the positive environmental impact achieved by using electric vehicles and smart charging strategies. By optimizing the charging and discharging patterns and integrating renewable energy sources with stationary battery storage systems, the overall carbon footprint of the electric vehicle ecosystem can be significantly reduced, contributing to a more sustainable and environmentally-friendly transportation system.

Table 19: Environmental KPI calculation for the performance of whole system

Test Case	Environmental KPIs
	Avoided CO2 amount (kg)
Environmental performance of whole system	351.35

- **Discussion**

The system performances were evaluated through tests conducted over a longer time period (1 month for battery and 2.5 month for DC charger) compared to the previously demonstrated short-term test cases. In this context, the following conclusions were drawn:

- The battery storage system and V2G charger were seamlessly coordinated for a full day through the local energy management platform, aligning with the DSO congestion management objectives. The assets responded rapidly and accurately to the designated setpoints. The feasibility of controlling different flexible assets together to reduce peak loads was demonstrated successfully.
- By shifting the charging process to nighttime and discharging during peak hours, specifically during midday and evening, it was shown that end-users can profit from the variability in spot market prices. Moreover, the potential to increase this profit through possible incentives offered by the DSO was emphasized.
- This comprehensive evaluation indicates that with efficient coordination and smart charging strategies, it is feasible to achieve congestion management goals, reduce peak loads, and provide benefits to both the grid system and end-users. Such results pave the way for more sustainable, cost-effective, and environmentally friendly energy management practices in the future.
- The battery storage system has demonstrated uninterrupted operation in load management due to its high availability rate and ability to respond swiftly. It has responded almost flawlessly to the designated setpoints during the specified peak times, showcasing its capability to provide long-term flexibility to the system. The system's excellent performance ensures a seamless response during peak periods, which is crucial for maintaining grid stability and efficient energy management.
- The impact of managing DC fast charging with smart algorithms on reducing peak loads has been demonstrated through extended studies. By slightly extending the charging time and reducing the average charging power, it is evident that the DSO can mitigate potential overload issues in the transformer load.
- Additionally, the combined operation of the battery storage system, designed to contribute to the charging process, has been shown to work effectively with the DC charger. During the smart charging operations, approximately 24% of the required energy was directly supplied from the battery storage system, highlighting its significant role in supporting the charging process.
- To emphasize the environmental impact of electric vehicles, the amount of CO2 emissions avoided during the charging processes compared to Internal Combustion Engine (ICE) vehicles has been calculated. This calculation was performed using the methodology described in the 2.1.1 Evaluation Method section, taking into account each operation conducted during the year 2023.

2.1.2.4 EV management platform and IoT platform evaluation

The EV management platform OEDAS served as the main platform used in the demos, alongside the design and integration work detailed in D8.2 and D8.3. All smart charging processes performed during the test cases were executed through the smart charging algorithm located in the back-end of the EV management platform. This platform facilitated seamless real-time control over all assets, ensuring smooth and efficient management of the electric vehicle charging processes.

In addition, as a result of the established structure and completed integrations, the IoT platform has been transformed into a monitoring platform for real-time tracking of assets and a management platform for external control in the OEDAS demos. The IoT platform has been fully integrated with the EV management platform primarily used in the OEDAS demo, allowing activities within the EV management platform to be triggered through the IoT platform.This integration enables the comprehensive evaluation of the process from both the FSP and DSO perspectives. It enables the management of the entire process using a single platform, integrating IoT capabilities, and providing efficient control and coordination between various assets and operations through the IoT platform.

In the final configuration, as depicted in Figure 9, an additional dashboard has been created to allow both the DSO and FSP to input smart charging settings. This dashboard facilitates the evaluation of the entered inputs by the smart charging algorithm within the EV management platform, enabling the creation of charging and discharging profiles for assets such as EV chargers and batteries.

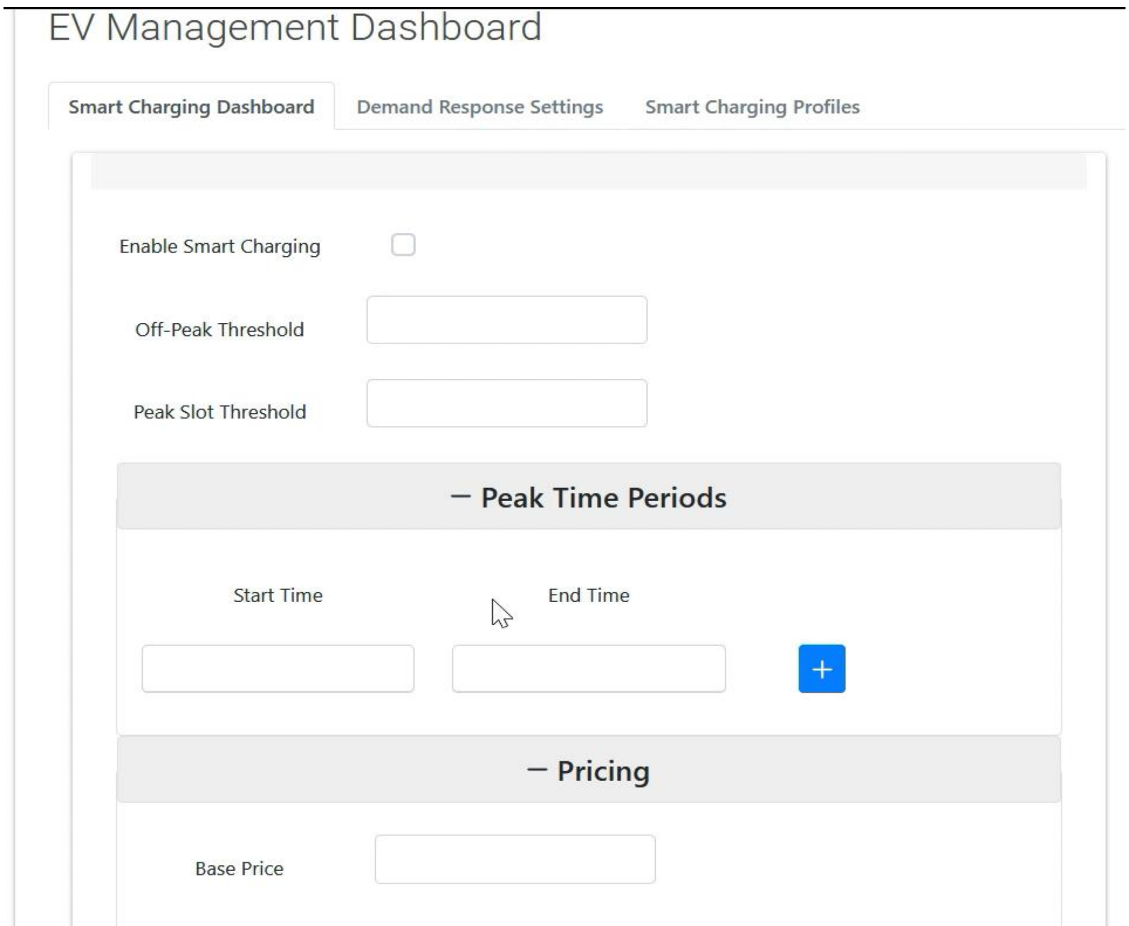

Figure 9 Smart charging section of IoT EV management dashboard

As a result of the entered settings, the calculated profiles have been visualized through the smart charging profiles section on the IoT platform's EV management dashboard (see an example in Figure 10). This visualization enables the monitoring of the process, allowing users to track and observe the smart charging profiles in real-time.

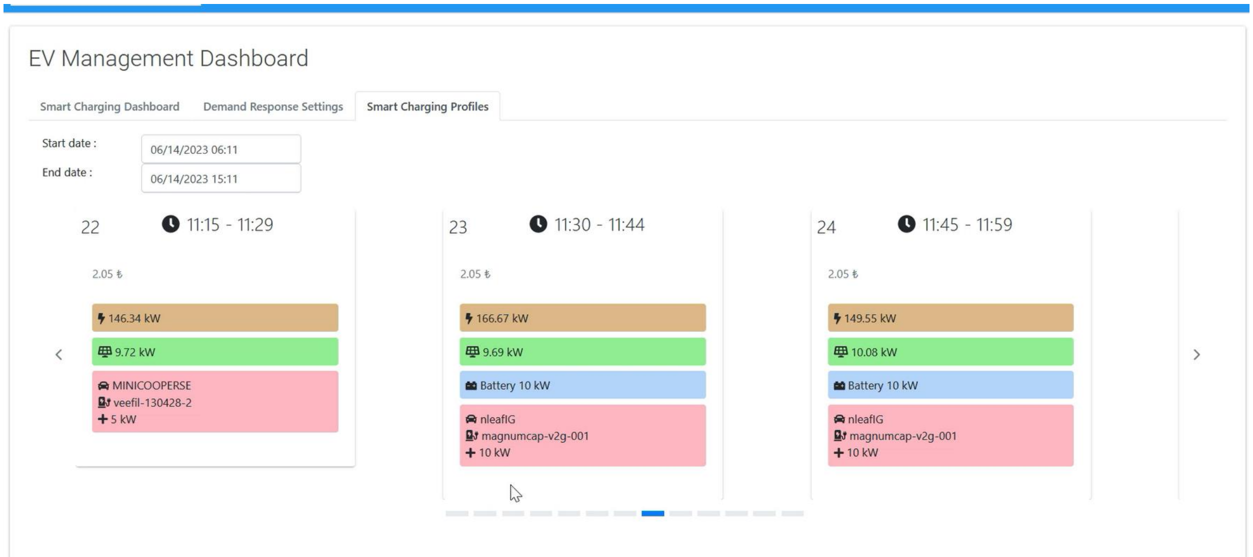

Figure 10 Smart charging profiles of EV management dashboard

An additional dashboard has been added to the IoT platform, allowing the DSO to specify its flexibility requirements and generate Demand Response signals accordingly (Figure 11). This enables the DSO to request flexibility at desired time intervals and manage the process through the IoT platform.

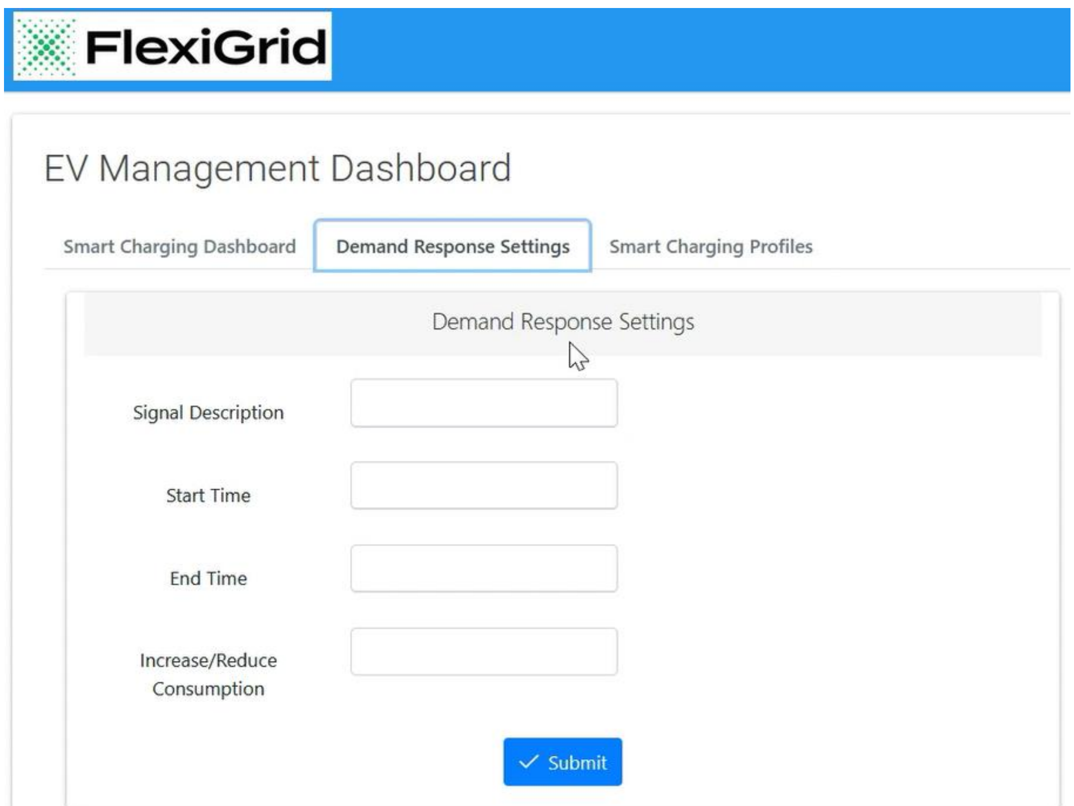

Figure 11 Demand Response section of IoT EV management dashboard

The EV management platform and the fully integrated IoT platform were actively used both in the test cases conducted within the scope of D8.3 and in the studies carried out as part of D8.4. Through the integration efforts, it was observed that the FlexiGrid IoT platform provided seamless monitoring and control capabilities, particularly in ensuring smart charging and grid flexibility processes.

2.2 Swiss pilot site

For evaluating the flexibility provided by controlling its assets, HES conducts two main evaluations: an economic evaluation and a reliability (i.e., technical performance) evaluation.

1. Economic Evaluation: The economic evaluation assesses the cost, remuneration, penalty, and revenue from the perspective of HES (as a flexibility service provider) for each test case. This evaluation aims to determine the financial implications and benefits associated with the implementation of flexibility. It involves analyzing the costs incurred during the assets' lifetime / operation, evaluating the potential income generated through the utilization of these assets, and considering any penalties that may arise due to deviations from standard operations. By conducting a thorough economic evaluation, HES can gain insights into the financial viability and profitability of the proposed flexibility solutions.

2. Reliability Evaluation: The reliability evaluation focuses on assessing the reliability and dependability of the HES in providing flexibility through the control of its assets. This evaluation aims to ensure that the HES can consistently deliver the desired flexibility services without compromising the overall performance and stability of the system. It involves analyzing the reliability metrics, such as Flexibility Deviation Ratio (FDR), Predicted Flexibility Reliability (PFR) and Flexibility Availability Index (FAI). By conducting a comprehensive reliability evaluation, HES can identify any potential shortcomings in the system's operation and make necessary improvements to enhance its overall reliability.

Overall, these two evaluations, economic and reliability, will provide a comprehensive understanding of the financial implications and the performance capabilities of HES, enabling informed decision-making regarding the usage of the system for flexibility supply purposes.

2.2.1 Flexibility evaluation method

- **Economic analysis:**

i. Cost:

To obtain a comprehensive analysis of the cost of flexibility, we employ two distinct approaches based on the situation at hand.

1) The first approach assumes that the asset is solely dedicated to providing flexibility. Consequently, we consider the total cost, encompassing both the Levelized Cost of Storage/Energy (LCOS/LCOE) and operational costs. This approach considers all relevant factors related to the asset's utilization and provides a comprehensive assessment of its cost.
2) The second approach focuses exclusively on the operational costs associated with buying or selling energy (electricity and hydrogen) to or from the grid/Market. In this perspective, the cost implications are analyzed only in terms of energy transactions. By considering both approaches,

one can gain a more comprehensive understanding of the overall cost implications of employing flexibility in different scenarios.

To calculate the cost of HES for providing flexibility using a specific asset in each test case, the concept of levelized cost of storage/energy (LCOS/LCOE) is introduced. The LCOS is utilized when the asset in question is a storage system, such as a battery, while the LCOE is used when the asset is an energy production asset.

In this context, the LCOE determines the cost associated with the delivery of flexibility (for each kilowatt-hour) performed by HES. It integrates all system costs over the lifetime of the asset, and it serves as a suitable indicator to represent the costs associated with flexibility that HES must pay. It is defined as follows:

$$LCOE_{Asset} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{7}$$

The lifetime cost of each asset comprises its investment cost (I_t)) and maintenance cost (M_t), which are brought to the base year using the discount rate (r). The net present cost of the asset is used to calculate the lifetime cost of it. E_t is the annual energy provided by the asset of HES and it can be calculated in each test case.

On the other hand, there is an additional cost that HES incurs during the flexibility period. This cost is associated with the buying or selling of energy from or to the grid/market. The calculation of this cost involves multiplying the unit net price of buying or selling energy from or to the grid by the amount of energy consumed or generated during each hour of flexibility. Typically, the buying price for considered energy carriers is higher than the selling price, varying across different assets. Consequently, this cost leads to higher expenses for HES.

Finally, the cost of HES for providing flexibility in one hour by specific asset is calculate according to the following equation (TC denotes the specific test case):

$$Cost_{Flex,\ Asset} = LCOS_{Asset} \times \text{Flexible energy}_{TC,\ Asset} + (Price_{Buy,\ energy} - Price_{Sell,\ energy}) \times \text{Flexible energy}_{TC,\ Asset} \tag{8}$$

Remuneration:

To incentivize the participation of HES as a Flexibility Service Provider (FSP) in flexibility provision, it is necessary to establish an appropriate unit remuneration price. Determining the remuneration price is a critical challenge as it significantly impacts the economic feasibility of HES engaging in flexibility services. In this project, the focus is on identifying the critical remuneration price, which ensures that the revenue generated by HES for providing flexibility is zero. By setting this critical remuneration price, the revenue of HES will balance out, eliminating any profit or loss. Any remuneration price above or below this critical value will result in positive or negative revenue for HES, respectively. This approach aims to find an equilibrium point where the costs of HES match its remuneration from flexibility provision. This critical price of remuneration can be described as follows:

$$Critical\ Price\ of\ Remuneration_{asset} = \frac{Total\ Cost\ of\ Flexibility_{asset}}{Offered\ Flexible\ Energy_{asset}} \quad (9)$$

For a comprehensive understanding of the remuneration price options in various scenarios, the time series data for the Day Ahead Price, Swiss Grid Price, and the price of selling/buying electricity by HES are depicted in the Figure 12 and Figure 13. This data covers the period from January 1, 2023, to April 30, 2023. Figure 12 represents the scenario with a positive flexibility request. Here, the Swiss Grid Price represents a shortage of energy in the Balance Group (short price). In this case, HES needs to either reduce its energy consumption or increase energy production, resulting in selling electricity to the grid. This figure displays the HES selling price, which indicates the revenue generated by HES from selling electricity.

On the other hand, Figure 13 illustrates the scenario when there is a negative flexibility request from OIKEN, and the Swiss Grid Price reflects an excess of energy in the Balance Group (long price). In this situation, HES needs to consume more energy and, consequently, must buy electricity. The figure displays the HES buying price, which provides a better understanding of the scale of costs incurred by the HES for purchasing electricity compared to other prices.

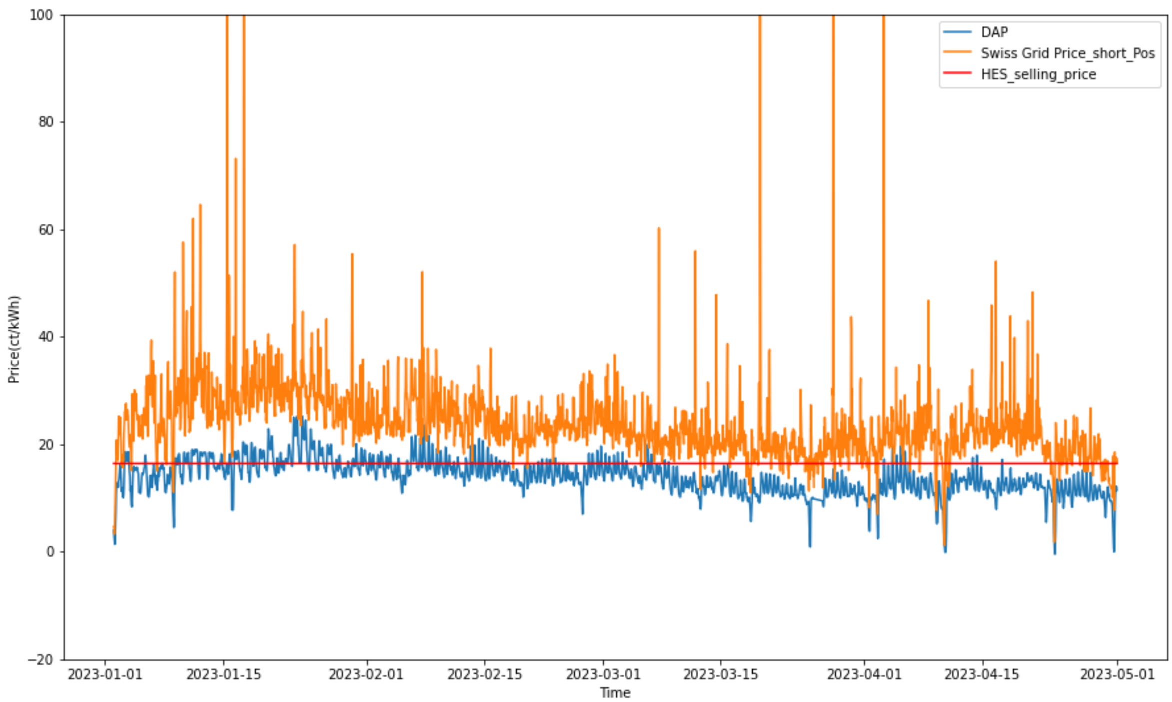

Figure 12 Comparison of Day Ahead Price, Swiss Grid Price_short, and Grid Electricity Selling Price for Positive Flexibility

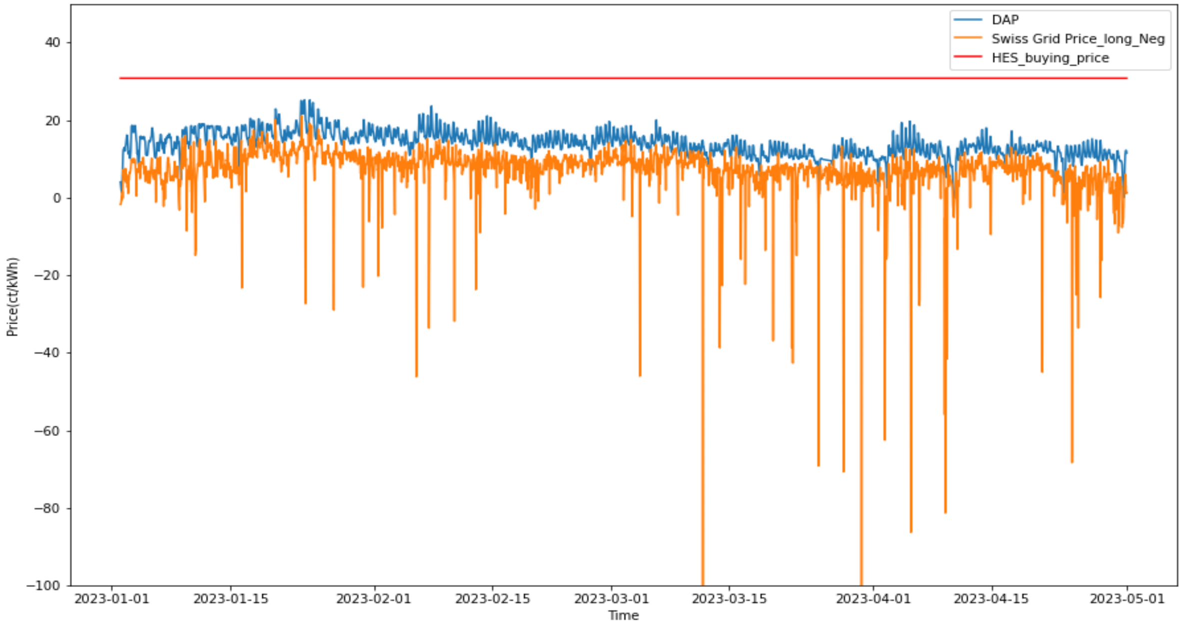

Figure 13 Comparison of Day Ahead Price, Swiss Grid Price_long, and Grid Electricity Purchase Price for Negative Flexibility

To assess the remuneration prices for each test case in specific hours of the day, it is necessary to determine the average remuneration prices for each time interval, specifically for each hour of the day. By utilizing a four-month time-series dataset, the Figure 14 and Figure 15 depict the moving average price for the Day Ahead Price, Swiss Grid Prices, and difference price of Day Ahead Price and Swiss Grid Prices, illustrating the moving average hourly values within a single day (24 hours). This moving average data can be utilized to evaluate the remuneration price of flexibility in both cases of positive and negative request, Figure 14 and Figure 15, respectively.

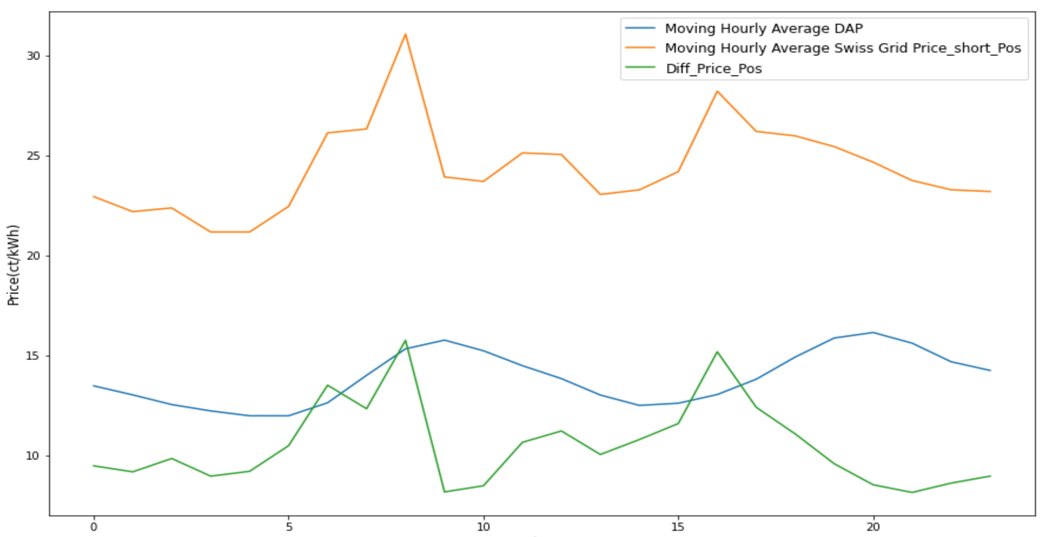

Figure 14 Average Hourly Prices: Day Ahead Price, Swiss Grid Price_short, and Price Difference (Day Ahead Price - Swiss Grid Price) for Positive Flexibility

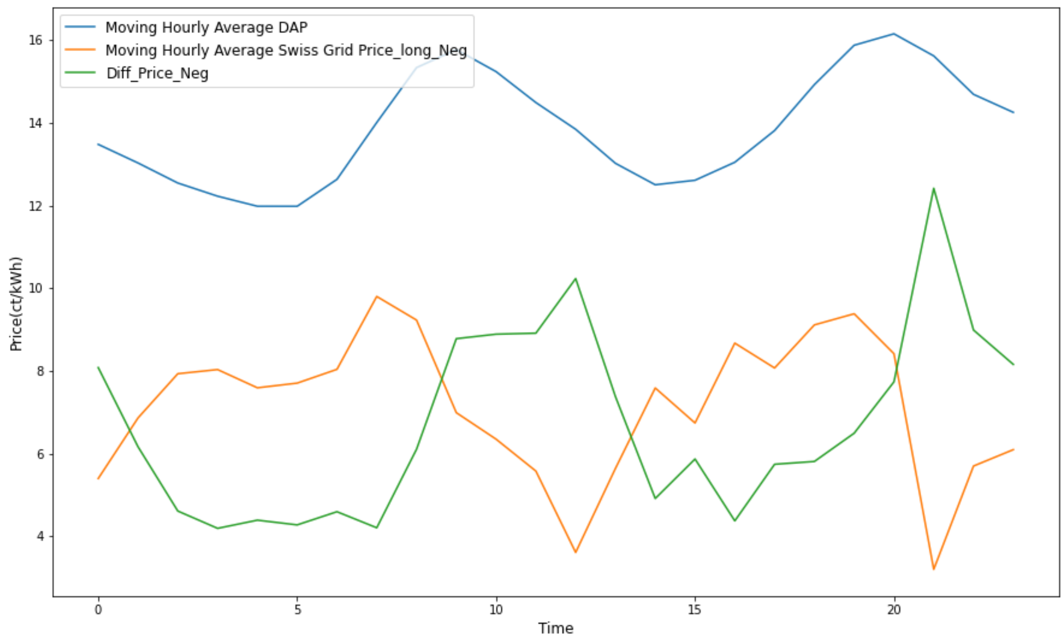

Figure 15 Average Hourly Prices: Day Ahead Price, Swiss Grid Price_long, and Price Difference (Day Ahead Price - Swiss Grid Price) for Negative Flexibility

It is important to emphasize that evaluating the remuneration for flexibility provision requires a comprehensive understanding of the flexibility situation (negative or positive), market infrastructure, and the dynamics of interactions among various market participants. This knowledge is crucial for accurately assessing the remuneration and ensuring that it aligns with the value of the flexibility service provided.

In the specific situation of FSP (HES), after evaluating multiple factors for determining unit remuneration prices for flexibility, it becomes necessary to choose a specific option as the remuneration price for the purpose of assessing all test cases consistently. As previously mentioned, the exact amount of remuneration for flexibility is still unclear, and it remains an interesting issue that warrants further investigation in future studies. Our current situation involves determining the remuneration amount for flexibility based on the interaction between FSP, OIKEN, and Swiss Grid. It is important to note that this is just one simple method, and determining the remuneration price requires considering numerous interactions and connections, making it a complex issue.

In our current setup, OIKEN, as a local DSO “D.8.3”, purchases a predetermined amount of electricity at the Day Ahead Price (DAP). During operation, if OIKEN consumes more electricity than the specific amount it bought from the DAP, it incurs additional costs for the excess energy at the Swiss Grid Short Price. Conversely, if OIKEN consumes less than the determined amount, it must sell the excess energy to Swiss Grid at the Swiss Grid Long Price. In such cases, FSP can intervene to assist OIKEN in these two situations:

1. If OIKEN experiences an energy shortage, FSP provides positive flexibility, preventing OIKEN from purchasing electricity at the higher Swiss Grid Short Price. Therefore, in this case, the cost savings would be the difference between the Swiss Grid Short Price and the DAP. This cost can be regarded as the added value of flexibility (remuneration price) that FSP contributes to the system.

$$\begin{cases} if\ there\ is\ energy\ shortage\ \rightarrow Positive\ Request\ AND\ \ if\ FSP\ provide\ energy\ shortage: \\ Price\ of\ remuneration\ _{Positive}(t) = \text{ Swiss Grid Short Price(t)} - DAP(t),\ \ t = time \end{cases} \tag{10}$$

2. If OIKEN has excess energy, FSP provides negative flexibility, preventing OIKEN from selling electricity at the lower Swiss Grid Long Price. Consequently, in this scenario, the cost savings would be the difference between the DAP and the Swiss Grid Long Price. This cost can be regarded as the added value of flexibility (remuneration price) that FSP contributes to the system.

$$\begin{cases} if\ there\ is\ \text{excess energy} \rightarrow Negative\ Request\ AND\ \ if\ FSP\ consume\ excess\ energy: \\ Price\ of\ remuneration\ _{Positive}(t) = DAP(t) - \text{ Swiss Grid Long Price(t)},\ \ t = time \end{cases} \tag{11}$$

Consequently, the price difference between the Day Ahead Price and Swiss Grid Price is considered as the remuneration price for HES in exchange of flexibility supply. Two factors are considered to establish this unit remuneration price: the time (hour of the day) at which each test case takes place and the type of flexibility required (positive or negative).

By considering these factors, the unit remuneration price can be determined based on the guidelines outlined in Figure 12 and Figure 13.

As a result, the total remuneration for each flexibility transaction is determined by multiplying the remuneration price (in CHF/kWh) with the total amount of flexibility energy planned by HES in its offer. These remunerations are presented in the following equations, considering whether the flexibility request is positive or negative:

$$\begin{aligned} Remuneration\ _{Positive} &= Flexible\ Energy\ _{Positive} \times\ Price\ of\ remuneration\ _{Positive} \\ Remuneration\ _{Negative} &= Flexible\ Energy\ _{Negative} \times\ Price\ of\ remuneration\ _{Negative} \end{aligned} \tag{12}$$

Penalty:

To calculate the penalty amount for flexibility provision, a contractual framework is necessary, which may vary depending on the situation. In the specific case of HES, there is a need to determine the penalty for the flexibility service provider based on the deviation of each energy unit from the planned flexibility offer during the provision of flexibility. As a result, a strategy referred to as the "*HES penalty cost calculation method*" is considered, as depicted in Figure 16. The basis of this strategy is around the remuneration payback from HES in the event of a penalty being imposed. According to this method, if the supplied flexible energy during each test case falls within the range of 95% to 105% of the predicted offer, no penalty needs to be paid, and the entire remuneration will be allocated to HES. However, if the supplied flexible energy falls outside of this range, HES will be required to pay a penalty. The penalty amount is calculated by multiplying the deviation percentage of the supplied flexible energy from planned flexibility offer by the supplied offer, just in case that the deviation would be outside the allowed range (more than + 5% or lower that -5%). To provide a clearer explanation, the equation for calculating the penalty is presented as follows:

$$\begin{cases} Deviation = 1 - \left(\frac{Supplied\ Flex\ Energy}{Offered\ Flex\ Energy}\right) \times 100 \\ if - 5\% \leq Deviation \leq\ 5\%\ \rightarrow Penalty = 0 \\ if\ Deviation\ > 5\ or\ Deviation\ < -5\%\ \rightarrow Penalty = (|Deviation| - 5\%) \times\ supplied\ Flex\ \frac{Energy}{100} \end{cases} \tag{13}$$

It should be noted that the method for calculating the penalty may differ depending on the specific situation. In such cases, a new calculation approach for the penalty needs to be considered.

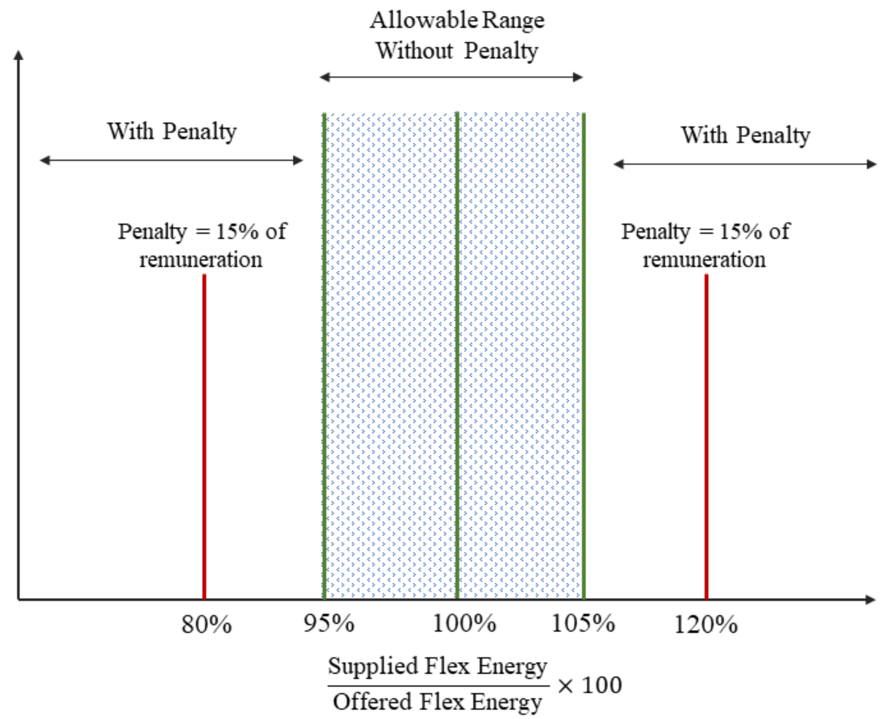

Figure 16 Calculation Method for Flexibility Service Provider Penalties

ii. Revenue:

Finally, for the final economic evaluation of providing flexibility, the revenue is determined from the perspective of HES as an FSP. This revenue represents the net revenue and profit for HES and it is calculated by subtracting the total cost and penalty from the total remuneration in each test case. In each test case, if the resulting revenue is positive, it indicates that providing flexibility in that case has an economic justification for HES. Conversely, if the revenue is negative, it signifies that the economic justification for providing flexibility is not present. For a more comprehensive evaluation, the revenue calculation considers two scenarios for cost considerations. In the first scenario, the total cost, which includes the Levelized Cost of Energy (LCOE) and operational costs, is considered. In the second scenario, only the operational costs are considered. This analysis aims to provide a thorough assessment of the economic feasibility of flexibility.

The revenue equation can be expressed as follows:

$$Revenue_{\ Test\ Case} = (\text{Remuneration} - \text{Cost} - \text{Penalty})_{\ Test\ Case} \tag{14}$$

➢ **Reliability analysis:**

To evaluate the reliability of the assets during the flexibility test cases, several KPIs have been introduced as metrics. These KPIs serve as essential indicators for assessing the system's performance and reliability in delivering the desired flexibility.

1) **Flexibility Deviation Ratio (FDR):** This index measures the deviation between the Predicted Flexibility Offer and the Supplied Flexibility Offer. It is calculated as the absolute difference between the two values divided by the Predicted Flexibility Offer as follows:

$$FDR = \frac{|\text{Supplied Flexibility Offer} - \text{Predicted Flexibility Offer}|}{\text{Predicted Flexibility Offer}} \times 100 \tag{15}$$

A lower FDR indicates a higher level of conformity between the predicted and actual flexibility values, indicating greater reliability in meeting the specified flexibility request.

2) **Predicted Flexibility Reliability (PFR):** This index is a metric that assesses the reliability of the predicted flexibility offered by a system. It measures the system's ability to consistently deliver the predicted levels of flexibility in response to the specified requirements.

$$PFR = 100 - (\frac{|\text{Supplied Flexibility Offer} - \text{Predicted Flexibility Offer}|}{\text{Predicted Flexibility Offer}} \times 100) \tag{16}$$

This metric evaluates the reliability of the asset and flexibility offered by an asset based on its predicted flexibility capabilities. The PFR assesses the system's ability to consistently deliver the predicted levels of flexibility. It considers factors such as the accuracy of predictions and the system's overall reliability in meeting the expected flexibility offer. A higher PFR value indicates a higher level of reliability in delivering the predicted flexibility, reflecting the system's consistent performance in meeting the predicted flexibility offer. It is basically the opposite of the Flexibility Deviation Ratio.

In addition, by evaluating the Predicted Flexibility Reliability (PFR) and Flexibility Deviation Ratio (FDR) metrics, one can assess the effectiveness of the flexibility potential algorithm developed to calculate the flexibility offer. This algorithm considers various factors, such as OIKEN's request, available assets, their status, and their shares for the flexibility offer. The PFR and FDR metrics allow to gauge the algorithm's capability in accurately predicting the flexibility offer and its reliability in aligning with the actual flexibility needs. A higher PFR value indicates a stronger alignment between the predicted flexibility offer and the actual requirements.

Flexibility Availability Index (FAI): This index assesses was introduced as "equation 2" in section 2.1. A higher FAI value indicates greater availability and reliability of the HES system in offering flexibility.

2.2.2 Flexibility Test-Cases Evaluation

2.2.2.1 TC 8.3 Reliable flexibility offer using batteries

- **Test case review**

As a part of D.8.3, Batteries are controlled to offer flexibility to OIKEN. One test is performed:

1) A positive flexibility request of 50kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of 17.36 kW and OIKEN accepts it. The baseline of the battery is 0kW. OIKEN accepts the offer, and the batteries offer flexibility. The flexibility offer with its request in this test case is presented in Figure 17. This test case was conducted at 11 AM.

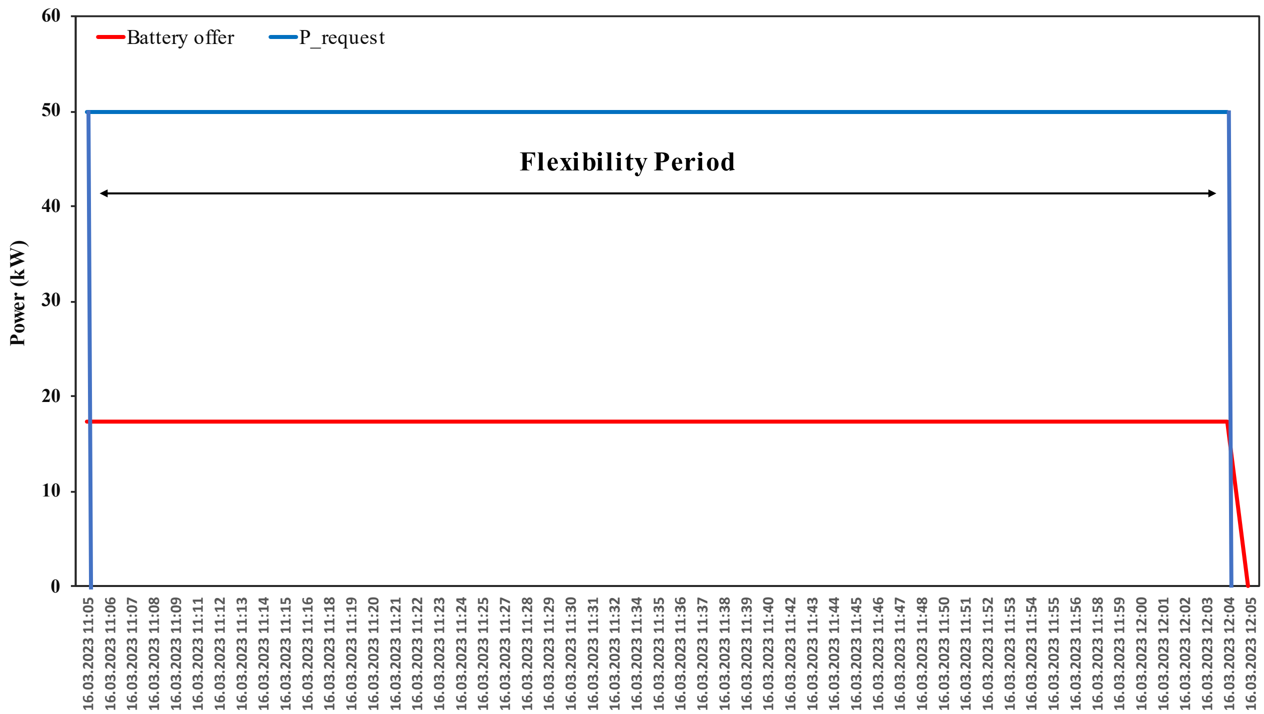

Figure 17 Flexibility offers in the test case "Reliable flexibility offer using batteries"

- **Proposed analysis method**

For the economic evaluation of the battery test case, it is necessary to calculate the levelized cost of storage (LCOS) for the batteries. To do so, the annual energy provided by the batteries needs to be determined. It is assumed that the battery undergoes 500 charge and discharge cycles per year (Al-Khori, Bicer and Koç 2021). The annual energy of the battery (E_t) can be calculated by multiplying the yearly cycles with the energy per cycle, considering limitations on the depth of discharge of the battery.

On the other hand, by analyzing the proposed reliability metrics in previous section, we can gain insights into the battery's capability to deliver the desired flexibility services in a reliable and timely manner. This evaluation considers factors such as the availability of the asset, its operational status, and its allocated shares for providing flexibility.
All of the parameters used for the economic and reliability evaluation of the test case of battery are presented in Table 20. It is important to note that the discount rates have been adjusted to the year 2022, taking into account the yearly inflation data from this site (Tradingeconomics).

Table 20 Parameters used for the evaluation of the flexibility test case involving batteries

Parameter	Value	Ref.	Parameter	Value	Ref.

Number of lifetime cycles	5000	(Al-Khori, Bicer and Koç 2021)	Day-ahead Price (11AM) (ctCHF/kWh)	14.49	-
Cycles per year	500	(Al-Khori, Bicer and Koç 2021)	Swiss Grid Price_short (11AM) (ctCHF/kWh)	25.15	-
Battery capacity (kWh)	264	-	Battery capital cost ($/kWh)	562	(Al-Khori, Bicer and Koç 2021)
Supplied flexible energy (kWh)	17.36	-	Exchange rate ($/CHF)	1.12	(Finance)
Grid electricity purchase price (CHF/kWh)	0.308	(Oiken)	Battery lifetime (year)	10	(Al-Khori, Bicer and Koç 2021)
Grid electricity selling price (CHF/kWh)	0.1645	(Oiken)	Discount rate (%)	7	(Henchoz, et al. 2015) (Tradingeconomics)

- **Results of analysis/evaluation**

For evaluating this test case, the quantitative techno-economic results for one hour of flexibility operation by the batteries are summarized in Table 21. The table provides key metrics such as Supplied Flexibility Offer (kWh), Predicted Flexibility Offer (kWh), calculated Levelized Cost of battery and its Critical Remuneration Price. The critical remuneration price is calculated in two scenarios:

- First Scenario: Total costs (levelized and operation cost) are considered.
- Second Scenario: Only operation costs are considered.

Table 21 Techno-economic results for test case of battery

Test cases	Flexibility Asset	Supplied Flexibility offer (kWh)	Predicted Flexibility offer (kWh)	LCOS (CHF/MWh)	Critical Remuneration Price (ctCHF/kWh)	
					Scenario 1	Scenario 2
Positive Request	Battery	17.36	17.36	169.9	28.44	14.35

To evaluate and compare the critical remuneration price of battery asset, which has been calculated according to section 1.2.1 (Flexibility Evaluation Method), with other remuneration price options, we need to determine the Day Ahead Price, Swiss Grid Price, and the price difference between these two prices during the flexibility test case. The positive request test case was conducted at 11 AM. Therefore, the displaying the comparison of remuneration prices is included in Figure 18.

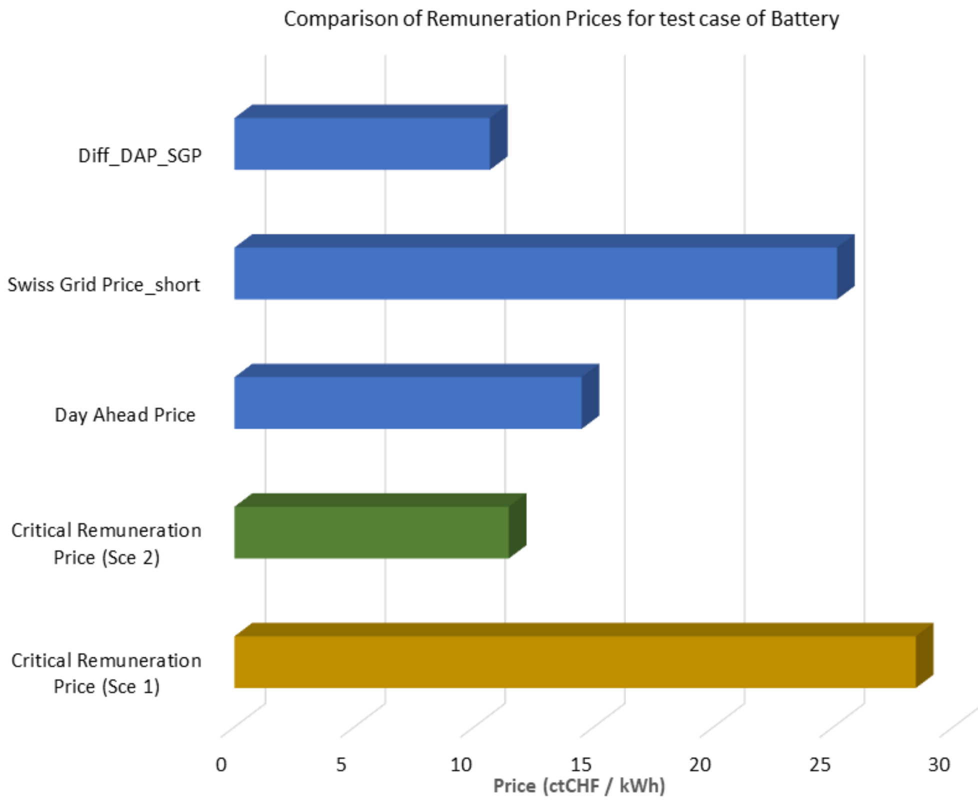

Figure 18 Comparison of remuneration prices for battery test case in positive flexibility request

For a more comprehensive analysis of the flexibility results, Table 22 provides the economic and reliability KPIs associated with this battery test case. It is worth mentioning that the remuneration and revenue calculations consider the price difference between the Day Ahead Price and Swiss Grid Price as the remuneration price. This price is determined according to Figure 14, considering the specific time of this test case.

Table 22 Economic and reliability KPIs of flexibility test case by battery

Test cases	Reliability (%)			Operation cost (CHF)	Total Cost (CHF)	Remuneration (CHF)	Penalty (CHF)	Revenue (CHF)	
	FDR	PFR	FAI					By operation cost	By total cost
Positive Request: Battery	0	100	100	3.62	5.441	1.89	0	-1.73	-3.551

- **Discussion:**

Based on the comparison of remuneration prices in Figure 18, it is evident that the critical remuneration prices for batteries in both scenarios are higher than the price differences between the Day Ahead Price and Swiss Grid Price. This indicates that using the price difference as the remuneration price does not provide economic justification for flexibility in the case of the battery.

On the other hand, according to the findings depicted in Table 22, it is evident that the battery exhibits a high reliability of 100% during flexibility operations, establishing its suitability as a controllable asset for providing flexibility services. However, the revenue generated by the batteries for flexibility purposes is negative, and it is not attractive from an economic standpoint. Furthermore, even when considering revenue only based on operational costs, the revenue remains negative, however at a reduced magnitude compared to the case considering total costs. Although the reliability of the battery is deemed acceptable, the current values for remuneration and system costs do not justify its use specifically for flexibility purposes.

Each flexibility provision by the battery imposes one cycle on the battery, and this cycle is factored into the LCOE (Levelized Cost of Energy) for the battery. Another cost consideration is when the battery is charged, the price of buying electricity is higher than the price of selling electricity during discharging time. As a result, the total cost of flexibility will be more than the received remuneration, it leads to a negative revenue for the battery.

It is worth mentioning that in the second scenario, both the Day Ahead Price (DAP) and the Swiss Grid Price are higher than the critical remuneration of the battery. Consequently, if either the DAP or the Swiss Grid Price is considered as the remuneration price for battery flexibility, it results in a positive revenue for the FSP side. This economic justification holds true, as well as reliability justification. As mentioned earlier, the determination of the remuneration price is a critical issue that significantly affects the economic feasibility of flexibility services. In summary, while the battery demonstrates satisfactory reliability, the current economic analysis reveals that it does not offer sufficient economic justification for deploying it solely for flexibility goals.

2.2.2.2 TC 8.4 Reliable flexibility offer using heat-pumps

- **Test case review**

As a part of D.8.3, The heat pump of building 19 is controlled to offer flexibility to OIKEN. Two tests are performed:

1. A positive flexibility request of 50kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of 31.6kW and OIKEN accepts it. This test case was conducted at 9:05 AM.
2. A negative flexibility request of -50kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of -30.28 kW and OIKEN accepts it. This test case was conducted at 9:50 AM.

In another configuration, the heat pump of building 23 is controlled to offer flexibility to OIKEN. Two other tests are performed:

1. A positive flexibility request of 35kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of 28.92kW and OIKEN accepts it. This test case was conducted at 12:05 PM.
2. A negative flexibility request of -23kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of -19.33 kW and OIKEN accepts it. This test case was conducted at 9:30 AM.

The flexibility offers in the test cases involving heat pumps of building 19 and building 23 are depicted in Figure 19 for both positive and negative requests.

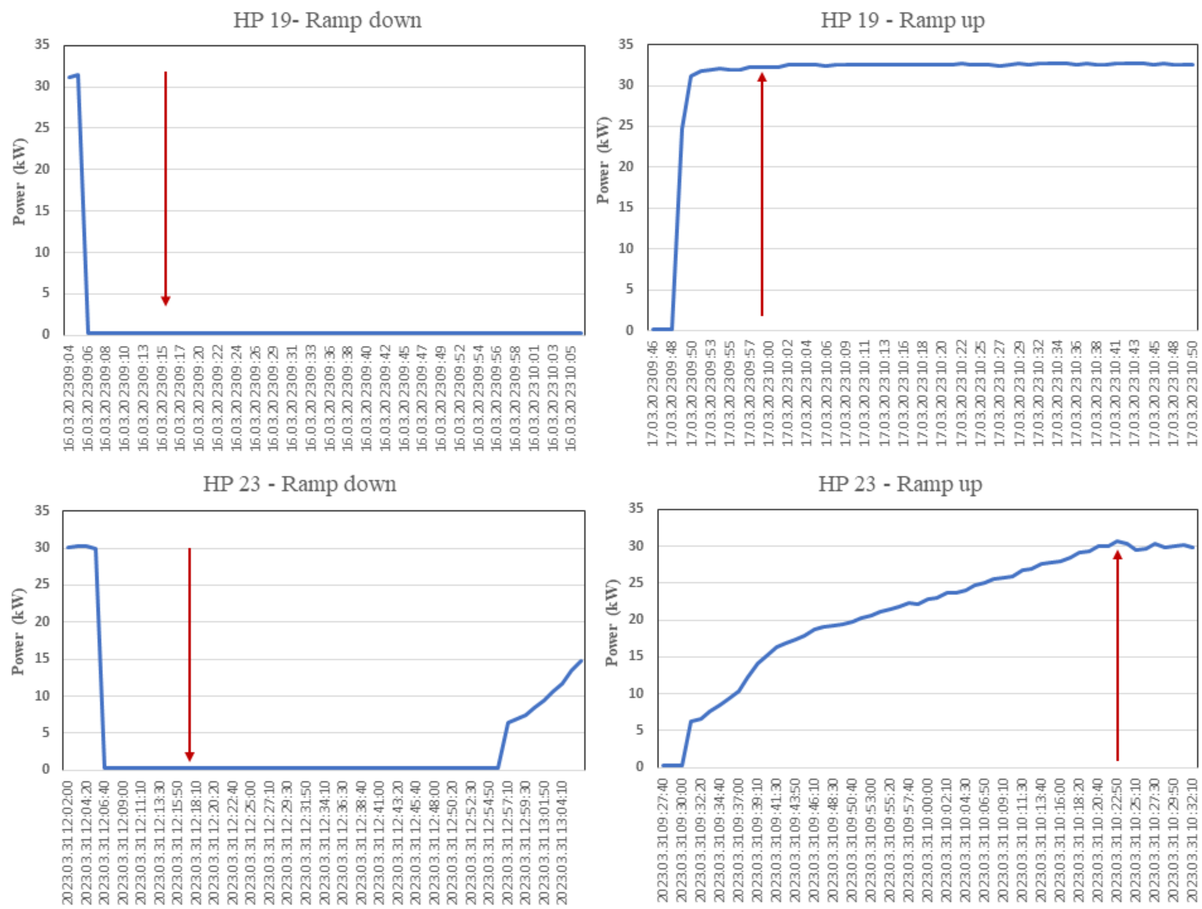

Figure 19 Flexibility offers in test cases of heat pumps of building 19 and building 23

- **Proposed analysis method**

For the economic evaluation of the heat pump (HP) test cases, it is important to acknowledge that providing flexibility through HPs involves shifting their operation time from the normal schedule. However, this non-normal operation has consequences, including a decrease in the optimal COP of the HPs and potential discomfort due to deviations from the desired indoor temperature. To calculate the cost associated with providing flexibility using the heat pump, we can consider a conservative estimate of a 20% decrease in COP and calculate the cost of excess energy consumption during non-optimal operating hours (Fischer, Wolf and Triebel 2017). This cost would reflect the additional energy consumed by the HPs during flexibility periods compared to their regular operation.

Furthermore, to provide a more comprehensive evaluation, the Levelized Cost of Energy (LCOE) of the HPs is considered, in a separate scenario. This makes it possible to assess the overall cost of energy production and of HPs' operation over their whole lifetime, considering factors such as capital costs, maintenance, and energy efficiency. By incorporating the LCOE, the long-term economic viability of using HPs for flexibility provision can be assessed.

All parameters used for the economic and reliability evaluation of the HPs test cases are presented in Table 23Table 20.

Table 23 Parameters used to analyze the test cases involving heat pumps of building 19 and 23

Parameter	Value	Parameter	Value	Ref
HP_19 capacity (kW_{el})	35	Day ahead Price (12 AM) (ctCHF/kWh)	13.85	-
HP_21 & HP_23 capacity (kW_{el})	30	Swiss Grid Price_short (9 AM) (ctCHF/kWh)	23.95	-
Supplied flexible energy, hp19_down: Positive request (kWh)	31.5	Swiss Grid Price_long (10 AM) (ctCHF/kWh)	6.35	-
Supplied flexible energy, hp19_up: Negative request (kWh)	30.28	Swiss Grid Price_short (12 AM) (ctCHF/kWh)	25.07	-
Supplied flexible energy, hp23_down: Positive request (kWh)	26.92	Swiss Grid Price_long (9:30 AM) (ctCHF/kWh)	6.67	-
Supplied flexible energy, hp23_up: Negative request (kWh)	21.28	Capital cost_HPs	Using an cost equation	(Henchoz, et al. 2015)
Day ahead Price (9 AM) (ctCHF/kWh)	15.77	Annual maintenance Cost_HPs: % of investment cost (CHF/year)	4	(Henchoz, et al. 2015)
Day ahead Price (9:30 AM) (ctCHF/kWh)	15.50	HPs lifetime (year)	15	(Henchoz, et al. 2015)
Day ahead Price (10 AM) (ctCHF/kWh)	15.24	Discount rate	0.07	(Henchoz, et al. 2015) (Tradingeconomics)

- **Results of analysis/evaluation**

The quantitative techno-economic results for one hour of flexibility operation by the HPs are summarized in Table 24. The table provides key metrics such as Supplied Flexibility Offer (kWh), Predicted Flexibility Offer (kWh), calculated Levelized Cost of HPs and its Critical Remuneration Price. The critical remuneration price is calculated just based on the operation cost.

Table 24 Techno-economic results for test cases of HPs

Test cases	Asset	Supplied Flexibility offer (kWh)	Predicted Flexibility offer (kWh)	LCOE (CHF/kWh)	Critical Remuneration Price (ctCHF/kWh)
Positive Request	HP 19	31.50	31.60	0.105	6.02
	HP 23	26.92	28.92	0.111	6.02
Negative Request	HP 19	30.28	30.28	0.105	6.02
	HP 23	21.28	19.33	0.111	6.02

To evaluate and compare the critical remuneration price of the HP asset with other remuneration price options, Figure 20 is provided for analysis.

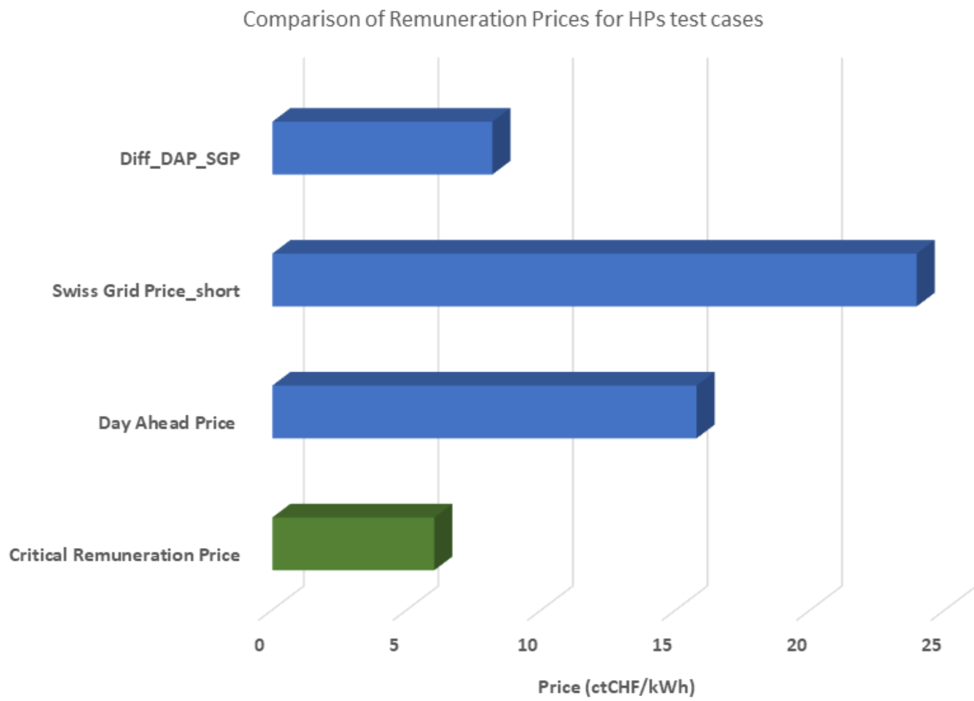

Figure 20 Comparison of remuneration prices for HPs test cases in positive flexibility request

For a more comprehensive analysis of the flexibility results, Table 25 provides the economic and reliability KPIs associated with these test cases of HPs. It is worth mentioning that the remuneration and revenue calculations consider the price difference between the Day Ahead Price and Swiss Grid Price as the remuneration price.

Table 25 Economic and reliability KPIs of flexibility test cases by HPs

Test cases	Asset	Reliability (%)			Operation cost (CHF)	Total Cost (CHF)	Remuneration (CHF)	Penalty (CHF)	Revenue (CHF)
		FDR	PFR	FAR					
Positive Request	HP 19	0.32	99.68	98.33	1.89	5.22	2.58	0	0.69
	HP 23	6.92	93.08	85	1.62	4.62	3.02	0.058	1.342
Negative Request	HP 19	0	100	100	1.82	5.02	2.69	0	0.87
	HP 23	9.16	90.84	100	1.28	3.65	1.88	0.078	0.6

- **Discussion**

Based on the comparison of remuneration prices in Figure 20, it is evident that the critical remuneration prices for the HPs are lower than the price differences between the Day Ahead Price and Swiss Grid Price. This indicates that using HPs for providing flexibility is economically justified when considering the price difference as the remuneration price.

On the other hand, the findings presented in Table 25 highlight that the HPs, particularly HP 23, exhibit lower reliability compared to the battery during flexibility operations. This suggests that the battery asset is more controllable and reliable for providing flexibility services. However, the test cases of HPs generate positive revenues, making them economically attractive. Unlike the battery asset, the HPs, especially HP 23, do not provide sufficient reliability justification for their use solely for flexibility purposes. In summary, while the HPs demonstrate satisfactory economic performance, the current reliability analysis indicates that they may not offer adequate reliability for deployment solely for flexibility goals. The suggestions for enhancing reliability KPIs for HPs are presented in the mitigation strategies of section "4.2 FSP side". HPs can be considered a viable option for flexibility provision, given their ability to operate between electrical and heating energy systems, effectively assessing the impact of these two systems on each other.

2.2.2.3. TC 8.5 Reliable flexibility offer using the power-to-gas platform

- **Test case review**

  In this test case, two set of test case are evaluated based on the sizes of P2G systems:

➢ **Small-scale**

The real small-scale 300W_{el} gas to power system (SOFC) has been run to offer flexibility for the positive requests from OIKEN. The flexibility that can be provided by this test case is showcased in Figure 21. This test was conducted at 3 PM.

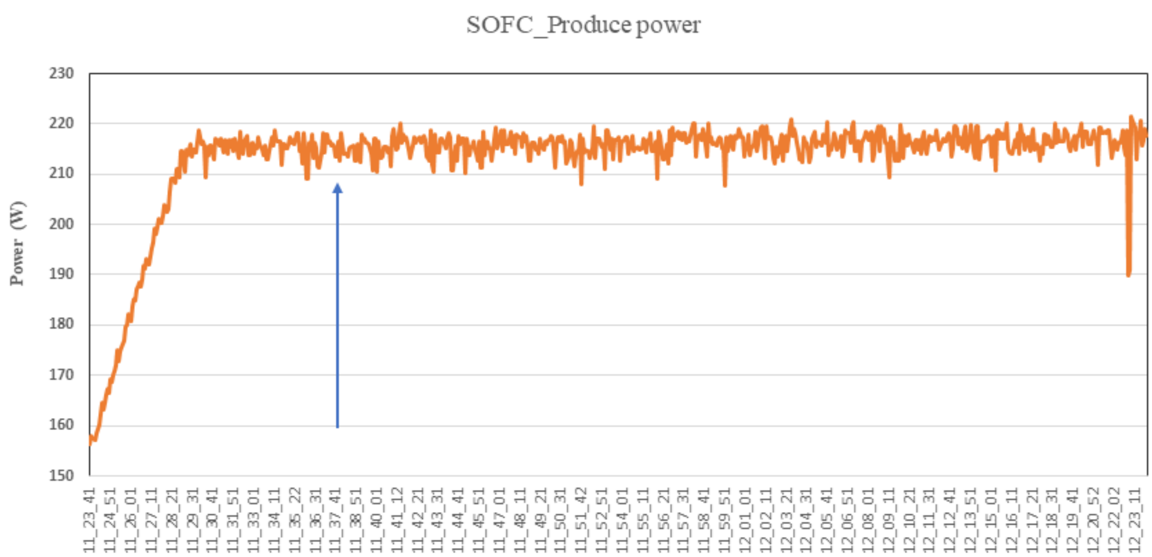

Figure 21 Flexibility providing by real test case of SOFC

➢ **Large-scale**

The simulated large-scale power to gas (SOEC) and gas to power (SOFC) systems, which are presented by details as a part of "D.8.3", are controlled to offer flexibility to OIKEN. Two tests are performed:

- A positive flexibility request of 8kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of 6.93kW by gas to power system (SOFC) and OIKEN accepts it. This test was conducted at 11 AM.

- A negative flexibility request of -24kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of -21kW by power to gas system (SOEC) and OIKEN accepts it. This test was conducted at 6 PM.

The flexibility provided by large-scale SOEC and SOFC are presented in Figure 22.

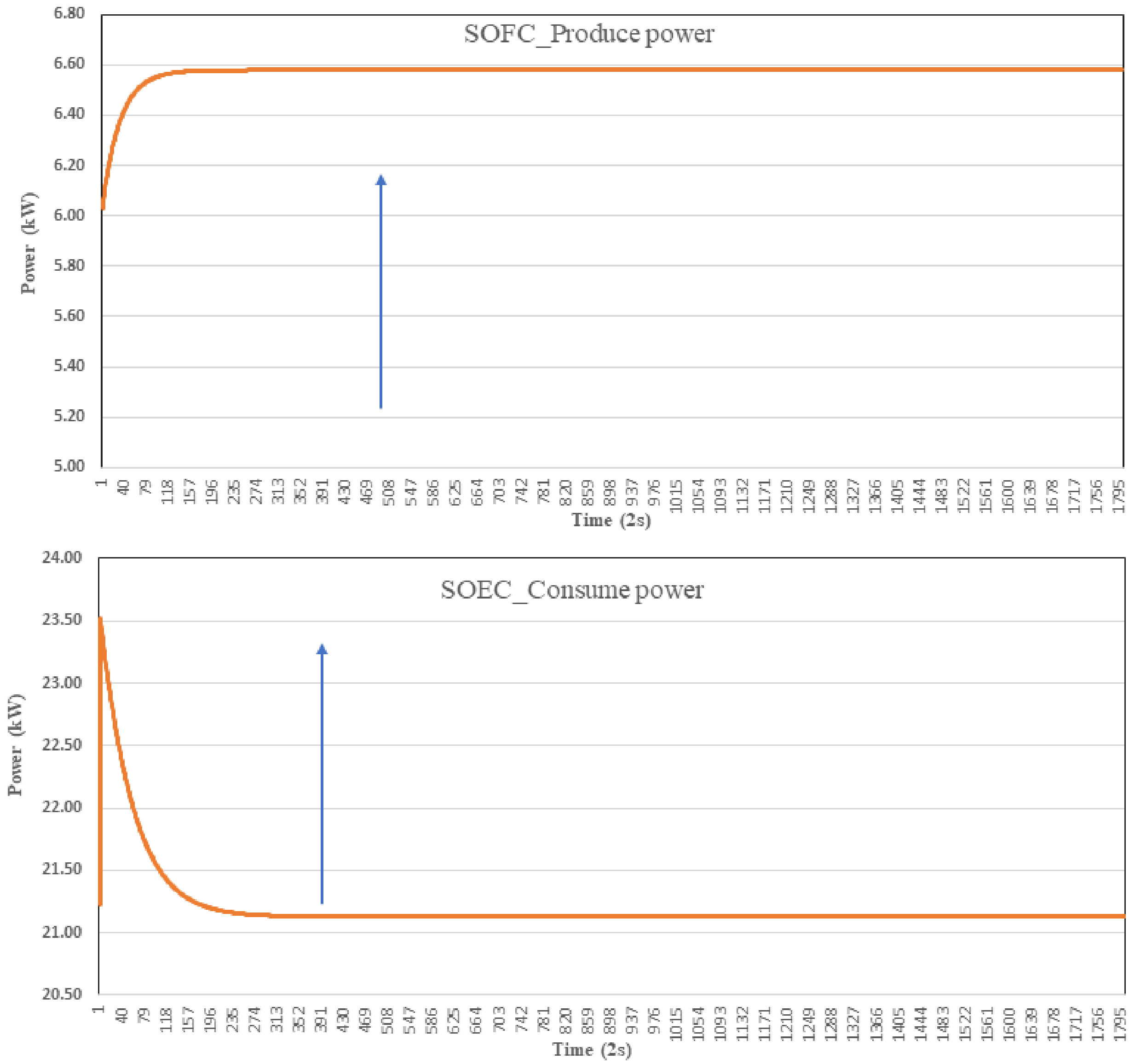

Figure 22 Flexibility of teste cases of large-scale SOEC and SOFC

- **Proposed analysis method**

In this test case, as well as for the battery system, the cost of providing flexibility on the HES side comprises two major components:

1) Levelized cost of energy produced by P2G systems: This cost reflects the expenses allocated for each kilowatt-hour (kWh) of energy produced by the Power-to-Gas (P2G) system over its

operational lifetime, particularly during flexibility periods. In this test case, the Levelized Cost of Energy (LCOE) is a major part of the economic evaluation of flexibility services (Section 2.2.1).

2) Operational costs during the flexibility period: For the Solid Oxide Fuel Cell (SOFC) system, which is considered as a flexibility asset for meeting positive requests, this cost includes expenses incurred by HES for purchasing hydrogen and revenue generated from selling the produced electricity back to the grid. For the Solid Oxide Electrolysis Cell (SOEC) system, which is considered as a flexibility asset for meeting the negative request, the operational cost is calculated based on the net cost of purchasing electricity from the grid and revenue generated from selling the produced hydrogen.

The sum of these two costs provides the total cost of HES for providing flexibility. The evaluation of these costs allows for a comprehensive understanding of the total cost associated with the flexibility delivery using the P2G systems.

In the case of a positive request, the remuneration is based on the amount of offered electricity that the SOFC system produces during the flexibility period. On the other hand, for a negative request, the remuneration is calculated based on the amount of offered electricity that the SOEC system consumes during the flexibility period. By considering these factors, the appropriate remuneration is calculated, considering the type of request, time of flexibility and the corresponding energy exchange offers by the SOFC and SOEC systems in the flexibility timeframe.

The revenue generated by HES Power-to-Gas (P2G) systems, is determined by subtracting the total cost and penalty from the total remuneration in both SOFC and SOEC test cases. The revenue calculation considers both the total cost and operational cost separately, enabling a comprehensive evaluation of the economic feasibility of flexibility provided by the P2G systems. For reliability assessment of P2G systems in flexibility services, availability metrics of SOFC and SOEC can be considered as KPIs for reliability assessment.

All parameters used for the economic and reliability evaluations of the test cases of the SOFC and the SOEC are presented in Table 26.

Table 26 Parameters of the P2G systems (SOFC and SOEC) used for the economic and reliability analysis

Parameter	Value	Ref.
Small-scale SOFC		
Inv. Cost of SOFC (Euro/kW)	6700	(Al-Khori, Bicer and Koç 2021)
Capacity of SOFC (W)	300	-
Supplied flex. energy (kWh/hr)	0.214	-
Consumption of H2 (litr/min)	2.68	-
LHV_H2 (kWh/kg)	33.33	-
Day ahead Price (3 PM) (ctCHF/kWh)	12.61	-
Swiss Grid Price_short (3 PM) (ctCHF/kWh)	24.21	-
Efficiency (%)	44.74	-
Large-scale SOFC		
Inv. Cost of SOFC (Euro/kW)	6700	(Al-Khori, Bicer and Koç 2021)
Yearly maintenance cost (% of investment cost)	6	(Al-Khori, Bicer and Koç 2021)
Capacity of SOFC (kW)	6	-
Supplied flex. energy (kWh/hr)	6.57	-
Consumption of H2 (litr/min)	105.13	-
Day ahead Price (11 AM) (ctCHF/kWh)	14.49	-
Swiss Grid Price_short (11 AM) (ctCHF/kWh)	25.15	-
Lifetime (year)	10	(Al-Khori, Bicer and Koç 2021)
Efficiency (%)	35	-
Large-scale SOEC		
Inv. Cost of SOEC ($/kW)	5685	(Kim, et al. 2021)
Yearly maintenance cost (% of investment cost)	5	(Kim, et al. 2021)
Capacity of SOEC (kW)	20	-
Supplied flex. energy (kWh/hr)	21.72	-
Production of H2 (litr/min)	79.52	-
Day ahead Price (6 PM) (ctCHF/kWh)	14.93	-
Swiss Grid Price_long (6 AM) (ctCHF/kWh)	9.12	-
Lifetime (year)	11	(Kim, et al. 2021)
Efficiency (%)	67	-
Common parameters (SOFC & SOEC)		
Capacity Factor (%)	50	(Hauch, et al. 2020)
Grid electricity purchase price (CHF/kWh)	0.308	(Oiken)
Grid electricity selling price (CHF/kWh)	0.1645	(Oiken)

Exchange rate (CHF to Euro)	0.97	(Tradingeconomics)
Hydrogen purchase price (CHF/kg)	10.9	(Wirth 2021)
Hydrogen selling price (CHF/kg)	10.9	(Wirth 2021)

- **Results of analysis/evaluation**

The quantitative techno-economic results for one hour of flexibility operation by the SOFC and SOEC are summarized in Table 27. The table provides key metrics such as Supplied Flexibility Offer (kWh), Predicted Flexibility Offer (kWh), Electricity/Hydrogen consumption/production, calculated Levelized Cost of P2G test cases along with their Critical Remuneration Prices. The critical remuneration prices are calculated in two scenarios:

- Critical remuneration prices: First Scenario, Total costs (levelized and operation cost) are considered.
- Critical remuneration prices: Second Scenario, Only operation costs are considered.

Table 27 Techno-economic analysis for P2G test cases in flexibility services

	Supplied Flexibility offer	Predicted Flexibility offer	Electricity consumption (-)/ production (+)	Hydrogen consumption (-)/ production (+)	LCOE (CHF/kWh)	Critical Remuneration Price (ctCHF/kWh)	
						Scenario 1	Scenario 2
SOFC 300 W	64.10 (Wh)	59.16 (Wh)	+64.10 (Wh)	-14.35 (gr)	0.285	85.19	56.64
SOFC 6 kW	6.57 (kWh)	6.93 (kWh)	+ 6.57 (kWh)	-0.5632 (kg)	0.285	105.32	76.98
SOEC 20 kW	21.72 (kWh)	21 (kWh)	-21.72 (kWh)	+ 0.426 (kg)	0.222	31.45	9.23

To evaluate and compare the critical remuneration price of P2G assets with other remuneration price options, the Day Ahead Price, Swiss Grid Price, and the price difference between these two prices during the flexibility test cases need to be estimated. The positive request test case by SOFC-300W_{el} was conducted at 3PM, the positive request test case by SOFC-6 kW was conducted at 10AM and the negative request test case by SOEC-20kW was conducted at 6PM. Therefore, a comparison of the remuneration prices is included in Figure 23.

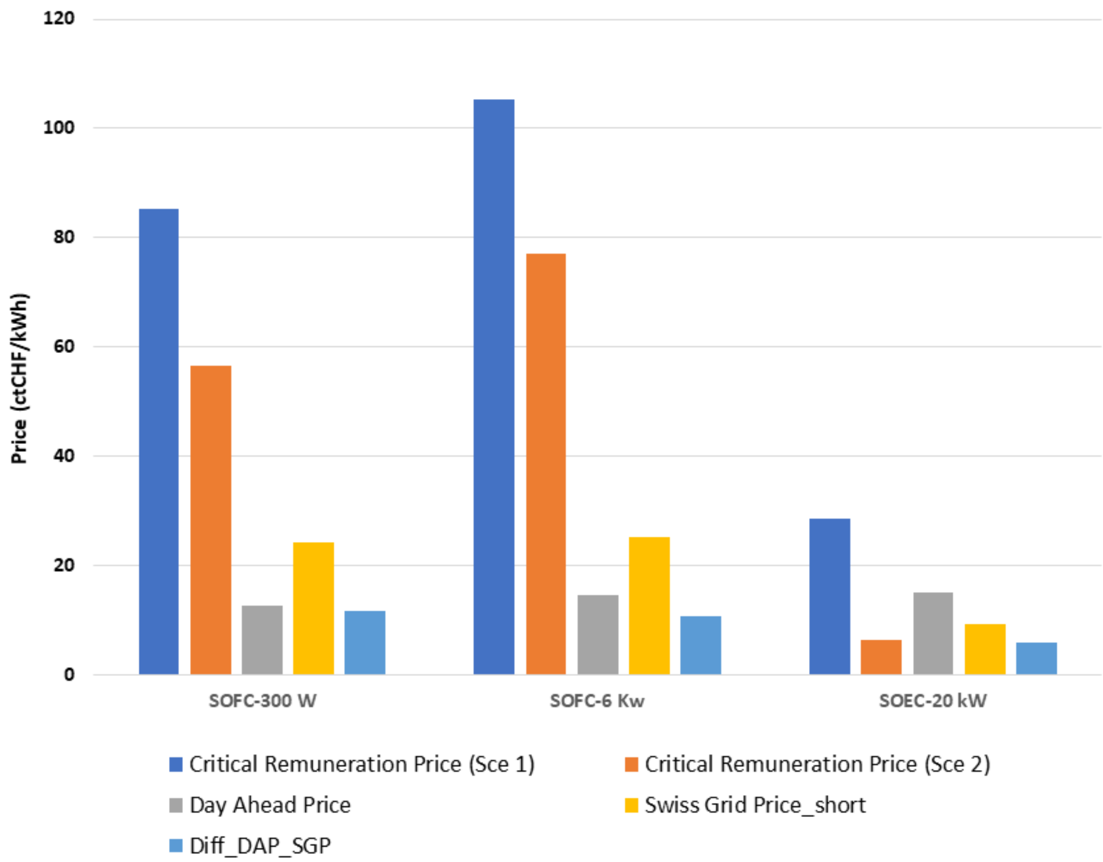

Figure 23 Comparison of remuneration prices for P2G test case in positive flexibility request

For a more comprehensive analysis of the flexibility results, Table 28 provides the economic and reliability KPIs associated with the P2G test cases. It is worth mentioning that the remuneration and revenue calculations consider the price difference between the Day Ahead Price and Swiss Grid Price as the remuneration price.

Table 28 Economic and reliability analysis for P2G test cases in flexibility services

Test cases	Reliability (%)			Operation cost (CHF)	Total Cost (CHF)	Remuneration (CHF)	Penalty (CHF)	Revenue (CHF)	
	FDR	PFR	FAI					By operation cost	By total cost
SOFC-300 W	7.71	92.29	99.16	0.1212	0.1823	0.0248	0.00067	-0.09707	-0.1575
SOFC-6 kW	5.2	94.80	100	5.0580	6.9334	0.70	0.00111	-4.3511	-6.2345
SOEC-20 kW	3.31	96.69	100	2.004	6.83	1.2619	0	-0.7421	-5.57

- **Discussion**

Based on the comparison of remuneration prices in Figure 23, it is evident that the critical remuneration prices for the SOFC asset are higher than for the SOEC in both scenarios. This indicates that the SOEC has stronger economic justification compared to the SOFC for providing flexibility. However, it should be noted that both P2G systems have critical remuneration prices higher than the price differences between the Day Ahead Price and Swiss Grid Price in both scenarios. This suggests that using the price difference as the remuneration price does not provide economic justification for flexibility in the case of the P2G systems.

On the other hand, according to the findings depicted in Table 28, the reliability and availability index for the P2G systems can be considered acceptable compared to HP systems, but they are not as controllable as the battery asset. However, the revenues generated by the P2G systems for flexibility purposes are negative, indicating that they are not economically attractive. Even when considering revenue based on operational costs only, the revenues remain negative, but at a reduced magnitude compared to the case where total costs were considered. In summary, while the P2G systems, particularly the SOEC, demonstrate acceptable reliability, the current economic analysis reveals that they do not offer sufficient economic justification for deploying them solely for flexibility purposes.

2.2.2.4 TC 8.6 Optimization of self-consumption

In this test case, different situations arise based on the time and status of the PV and battery assets, aligning with their respective operational objectives:

1) Self-Consumption: Batteries are charged by PV and subsequently discharged during non-flexibility periods.
2) Self-Consumption & Flexibility: Batteries are charged by PV and discharged during the flexibility period.
3) Flexibility: Batteries are charged by PV and discharged specifically during the flexibility period.

The mentioned situations along with their economic characteristics and parameters are presented in Table 29. The amount of flexible energy in this test case is 17.36, occurring at 10AM.

Table 29 Comparison the different situations of PV and Battery along with their economic characteristics

Situation	Economic Characteristics	Operation Cost (CHF) (Buy - Sell)	Remuneration (CHF)	Revenue (CHF)
Self-consumption	There is no buying cost for charging There is no remuneration	-2.8557	0	+ 2.8557
Self-consumption & Flexibility	There is no buying cost for charging There is a remuneration	-2.8557	1.4721	+ 4.3278
Flexibility	There is a buying cost for charging There is a remuneration	2.4912	1.4721	-1.02

To better analyze these situations, the economic indicators related to this test case include operation cost, remuneration and revenue, are plotted in Figure 24.

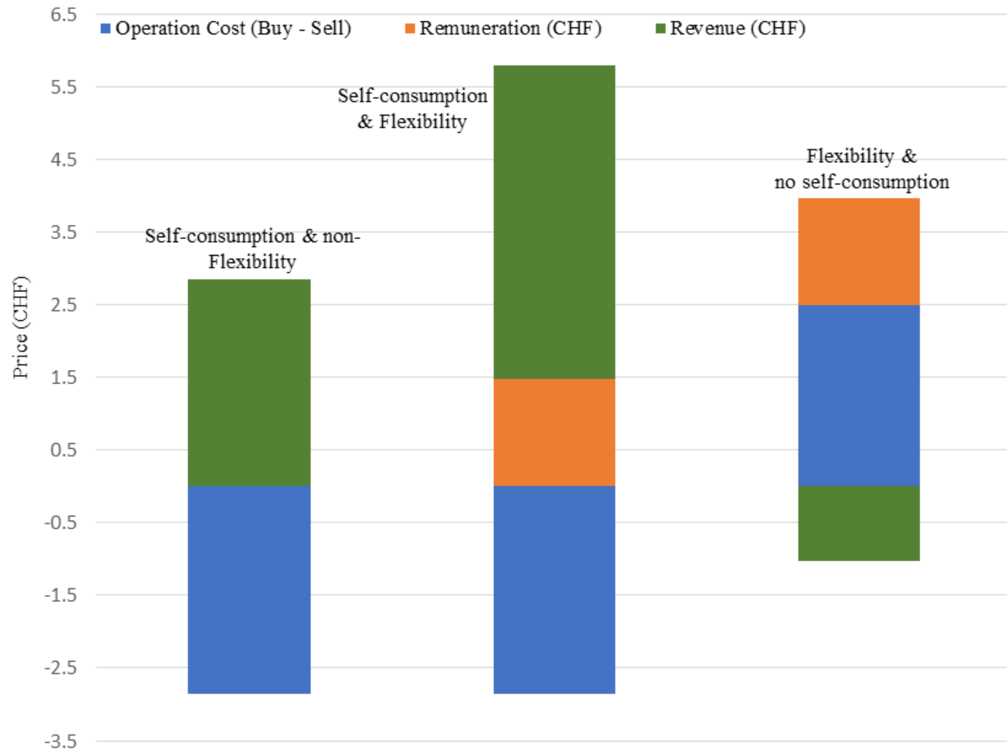

Figure 24 Comparison of economic indicators for flexibility & self-consumption situations

As seen in Figure 24 revenues for situations 1 and 2 are positive, representing self-consumption without and with flexibility, respectively. However, the highest revenue is associated with the second situation, where the battery is charged by PV and discharges its energy during the flexibility time. In this case, HES does not incur any costs for purchasing electricity, and on the other hand, it can receive remuneration by participating in flexibility through discharging the battery during the flexibility time. It is worth mentioning that in the third situation, where the battery is solely used for flexibility purposes, the revenue is slightly negative. From HES economic viewpoint, this situation lacks economic justification.

2.2.2.5 TC 8.7 Reliable flexibility offer using the whole system

- **Test case review**

➢ *Test case 1: Battery and HP 19*

In this test case, battery, and heat pump of building 19 are controlled to offer flexibility. A positive flexibility request of 50kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of 50kW and OIKEN accepts it. This test was conducted at 9:55 AM. The flexibility provided by Battery and HP_19 is presented Figure 25.

Figure 25 Flexibility of teste cases of Battery and HP_19 in one hour

- *Test case 2:* HP19, HP 21 and HP 23

In this test case, all heat pumps of building 19, building 21 and building 23 are controlled to offer flexibility to OIKEN. Two tests are performed:

1. A positive flexibility request of 65kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of 60.95kW and OIKEN accepts it. This test was conducted at 11:50 AM.
2. A negative flexibility request of -80kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of -68.95 kW and OIKEN accepts it. This test was conducted at 9 AM.

The flexibility provided by these test cases of HP_19, HP_21 and HP_23 is presented in Figure 26.

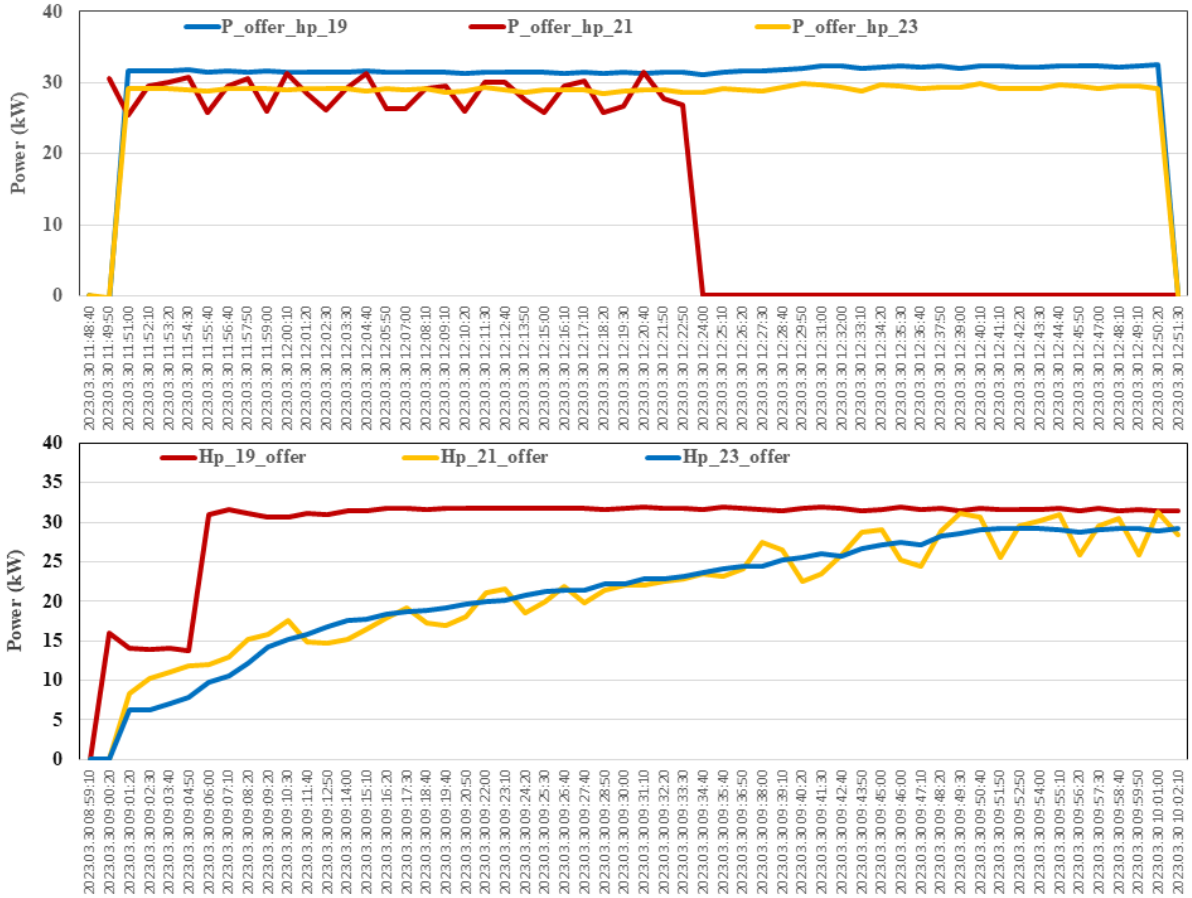

Figure 26 Flexibility of test cases of HP_19, HP_21 and HP_23 in one hour

- Test case 3: HP 19 + Battery + SOFC/SOEC:

This test case aims to showcase the potential of flexibility provided by the integrated operation of multiple assets within the Energypolis Campus, including batteries, heat pumps, and a P2G system. It demonstrates the capability of these assets to collectively offer flexibility services. The heat pump of building 19, batteries and P2G systems (SOFC and SOEC) are controlled to offer flexibility to OIKEN. Two tests are performed:

1. A positive flexibility request of 70kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of 70kW and OIKEN accepts it. This test was conducted at 9:45 AM.
2. A negative flexibility request of -50kW is posted by OIKEN. HES runs its flex offer generation algorithm, posts an offer of -30.28 kW and OIKEN accepts it. This test was conducted at 9 AM.

Figure 27 shows the flexibility provided by these test cases of HP 19, Battery and SOFC/SOEC .

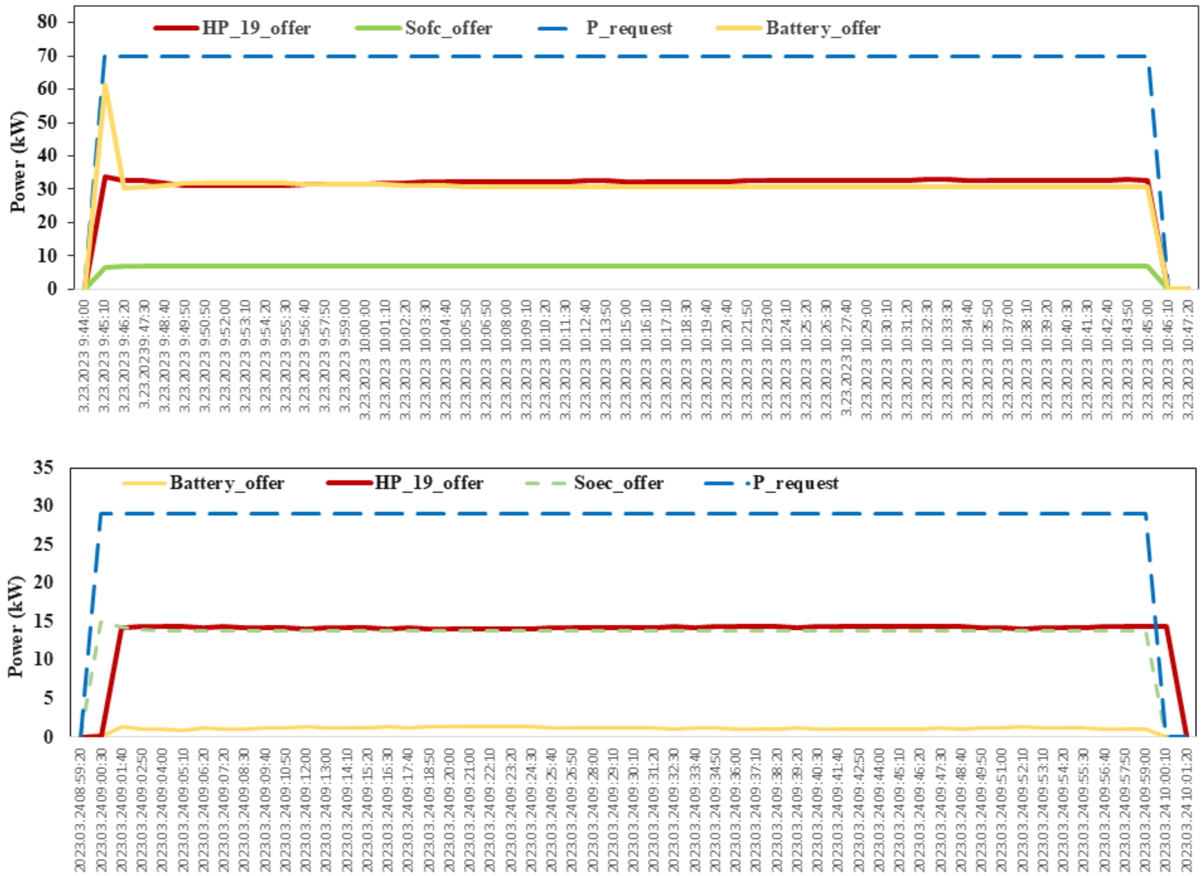

Figure 27 One-hour flexibility test cases involving integrated assets: HP_19, HP_21, and HP_23.

- **Proposed analysis method**

The technical and economic parameters which utilize in these test cases, determined in the previous assessments for each asset.

- **Results of analysis/evaluation**
  - *Test case 1: Battery and HP 19*

The quantitative techno-economic results for one hour of flexibility operation by the test case of battery and HP 19 are summarized in
Table 30. The table provides key metrics such as Supplied Flexibility Offer (kWh), Predicted Flexibility Offer (kWh), calculated Critical Remuneration Prices of battery/HP_19 test case. The critical remuneration prices are calculated based on operation cost.

Table 30 Techno-economic analysis for Battery/HP_19 test case in flexibility services

Test cases	Supplied Flexibility offer (kWh)	Predicted Flexibility offer (kWh)	Critical Remuneration Price (ctCHF/kWh)
Battery + HP_19	50.57	50	10.57
Battery share	27.242	26.29	14.35

HP_19 share	23.3272	23.71	6.02

For a more comprehensive analysis of the flexibility results, Table 31 provides the economic and reliability KPIs associated with Battery/HP_19 test case. It is worth mentioning that the remuneration and revenue calculations consider the price difference between the Day Ahead Price and Swiss Grid Price as the remuneration price.

Table 31 Economic and reliability analysis for Battery/HP_19 test case in flexibility services

Test cases	Reliability (%)			Operation Cost (CHF)	Total Cost (CHF)	Remuneration (CHF)	Penalty (CHF)	Revenue (CHF)	
	FDR	PFR	FAI					Operation cost	Total cost
Battery + HP_19	+1.14	98.86	100	5.34	12.43	4.29	0	-1.05	-8.14
Battery share	+3.6	96.4	100	3.90	8.54	2.31	0	-1.59	-6.23
HP_19 share	-1.6	98.4	66.66	1.44	3.89	1.98	0	+0.54	-1.91

- *Test case 1: Discussion*

Based on the economic and reliability analysis for this test case, it is evident that the presence of the battery asset significantly improves the reliability of the entire system in providing flexibility, achieving a reliability level of 100%. The battery compensates for the inefficiency of the HPs in terms of reliability, enhancing the overall performance of the system. From an economic perspective, while the revenue generated by the combined system of the battery and HP19 is still negative, it is better than the revenue generated by the battery asset alone. This indicates that the HP19 contributes to the economic justification of the system. The combination of the battery and HP19 not only enhances the reliability of the system but also improves its economic viability.

Overall, the analysis highlights the synergistic effects of integrating the battery and HP19 in terms of reliability and economic performance in providing flexibility services. The battery helps increase the system's reliability, while the HP19 contributes to its economic justification.

- *Test case 2: HP_19, HP_21 and HP_23*

The quantitative techno-economic results for one hour of flexibility operation by the test case of all HPs are summarized in Table 32. The table provides key metrics such as Supplied Flexibility Offer (kWh), Predicted Flexibility Offer (kWh), calculated Critical Remuneration Prices of al HPs test case. The critical remuneration prices are calculated based on operation cost.

Table 32 Techno-economic analysis for all HPs test cases in flexibility services

Test cases	Assets	Supplied Flexibility offer (kWh)	Predicted Flexibility offer (kWh)	Critical Remuneration Price (ctCHF/kWh)
Positive Request	HP_19 + HP_21 +HP_23	75.54	60.95	6.02
	HP_19 share	31.15	31.6	-
	HP_21 share	15.80	0.3	-
	HP_23 share	28.59	29.07	-
Negative Request	HP_19 + HP_21 +HP_23	72.19	68.95	6.02

	HP_19 share	29.95	30.28	-
	HP_21 share	21.17	19.33	-
	HP_23 share	21.07	19.33	-

For a more comprehensive analysis of the flexibility results, Table 33 provides the economic and reliability KPIs associated with all HPs test case.

Table 33 Economic and reliability analysis for all HPs test cases in flexibility services

Test Cases	Assets	Reliability (%)			Operation Cost (CHF)	Total Cost (CHF)	Remuneration (CHF)	Penalty (CHF)	Revenue (CHF)	
		FDR	PFR	FAI					Operation cost	Total cost
Pos	HP19+HP21 +HP23	+23.93	76.07	55	4.65	12.84	8.52	1.61	+2.26	-5.93
	HP_19 share	-1.4	98.6	100	1.92	5.19	3.5	0	+1.58	-1.69
	HP_21 share	+5166	5266	55	0.973	2.72	1.77	-	-	-
	HP_23 share	-1.65	98.35	100	1.76	4.93	3.21	0	+1.45	-1.72
Neg	HP19+HP21 +HP23	+ 4.7	95.30	93.33	4.45	12.26	6.34	0	+1.89	-5.92
	HP_19 share	- 1.09	98.91	93.33	1.84	4.98	2.63	0	+0.79	-2.35
	HP_21 share	+ 9.52	90.48	98.33	1.30	3.65	1.86	0.084	+0.476	-1.874
	HP_23 share	+ 9	91.00	98.33	1.29	3.63	1.85	0.074	+0.486	-1.854

- *Test case 2: Discussion*

Based on the economic analysis for this test case, the integration of different HPs results in a higher and positive revenue compared to individual HP test cases in flexibility provision. The reason is that the integrated HPs are able to provide a greater amount of flexible energy. This indicates that combining multiple HPs can offer economic advantages and increase the overall performance of the system in terms of revenue generation.

However, from a reliability standpoint, integrating multiple HPs presents a challenge in terms of control and coordination. This challenge leads to a decrease in the reliability index of the integrated HPs in flexibility services, particularly in situations with positive requests, when compared to the HP assets alone. While the integration can provide economic benefits in terms of revenue, there is a trade-off in terms of reliability.

- *Test case 3: HP_19, Battery and P2G systems*

The quantitative techno-economic results for one hour of flexibility operation by the test case of HP_19, Battery and P2G systems are summarized in Table 34. The table provides key metrics such as Supplied Flexibility Offer (kWh), Predicted Flexibility Offer (kWh), calculated Critical Remuneration Prices of this test case. The critical remuneration prices are calculated based on operation cost.

Table 34 Techno-economic analysis for test case of HP_19, Battery and P2G systems in flexibility service

Test cases	Assets	Supplied Flexibility offer (kWh)	Predicted Flexibility offer (kWh)	Critical Remuneration Price (ctCHF/kWh)
Positive Request	HP_19+Battery+SOFC	70.80	70	16.75
	HP_19 share	32.29	32.46	6.02
	Battery share	31.62	30.61	14.35
	SOFC share	6.93	6.93	76.95
Negative Request	HP_19+Battery+SOEC	28.64	29.00	7.68
	HP_19 share	13.97	13.23	6.02
	Battery share	1.12	2.21	14.35
	SOEC share	13.56	13.56	9.23

The comprehensive analysis of the flexibility results for test case of HP_19, Battery and P2G systems are provided in Table 35 which include the economic and reliability KPIs associated with this test case.

Table 35 Economic and reliability analysis for test case of HP_19, Battery and P2G systems in flexibility services

Test Cases	Assets	Reliability (%)			Operation Cost (CHF)	Total Cost (CHF)	Remuneration (CHF)	Penalty (CHF)	Revenue (CHF)	
		FDR	PFR	FAI					Operation cost	Total cost
Pos	HP_19+Battery+SOFC	+1.15	98.85	98.33	11.86	22.60	6	0	-5.86	-16.6
	HP_19 share	-0.52	99.48	97.5	1.99	5.38	2.74	0	+0.75	-2.64
	Battery share	+3.3	96.7	98.33	4.53	9.91	2.68	0	-1.85	-7.23
	SOFC share	0	100	100	5.33	7.31	0.588	0	-4.742	-6.722
Neg	HP_19+Battery+SOEC	-1.24	98.76	98.33	2.20	6.87	2.51	0	+0.31	-4.36
	HP_19 share	+5.6	94.4	98.33	0.86	2.33	1.23	0.0197	+0.35	-1.12
	Battery share	0	100	100	0.16	0.351	0.0983	0	-0.0617	-0.253
	SOEC share	0	100	100	1.18	4.19	1.19	0	+0.01	-3

➢ *Test case 3: Discussion*

In this test case, the revenue generated in the positive request scenario is negative, indicating a lack of economic justification for the flexibility service. This can be attributed to the high costs associated with the SOFC asset and the battery asset. However, in the case of a negative request, the total system revenue becomes positive, indicating economic viability for providing flexibility. In this scenario, the HP and the SOEC assets contribute to improving the revenue of the total system and offsetting the high cost of the battery. From a reliability perspective, both in the positive and negative request scenarios, the battery asset proves to be an efficient and controllable system. It helps to compensate for the inefficiencies of other assets, particularly the HPs, thereby increasing the overall reliability of the system.

It is important to consider both economic and reliability factors when evaluating the performance of the system in providing flexibility services. While the revenue may be negative in certain scenarios, the reliability benefits provided by the battery asset can contribute to the overall effectiveness and success of the flexibility service.

3. Electricity market compatibility

3.1 OEDAS pilot site

3.1.1 Turkish electricity market: Current situation, regulation, and legislation

The basic overview and key players regarding the structure of the Turkish electricity market are presented in Figure 28 and Figure 29. Details related to market structures are indicated with subheadings.

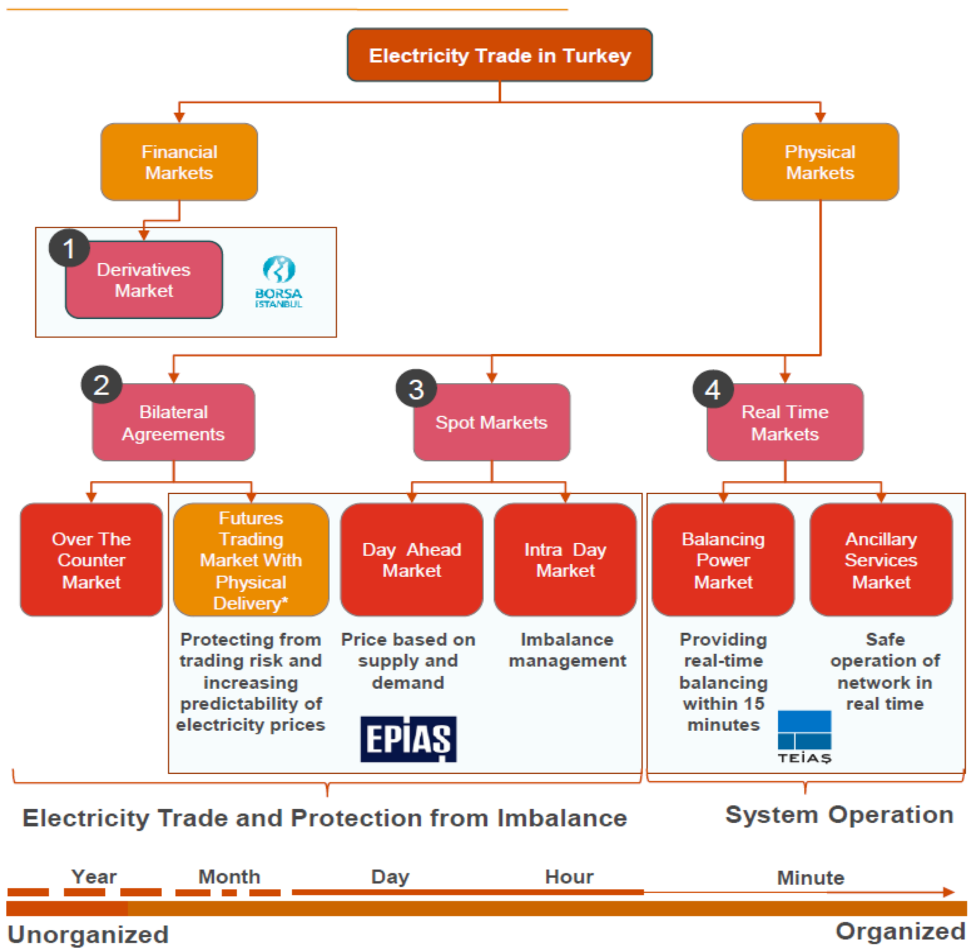

Figure 28 Turkish Electricity Market [Epiaş]

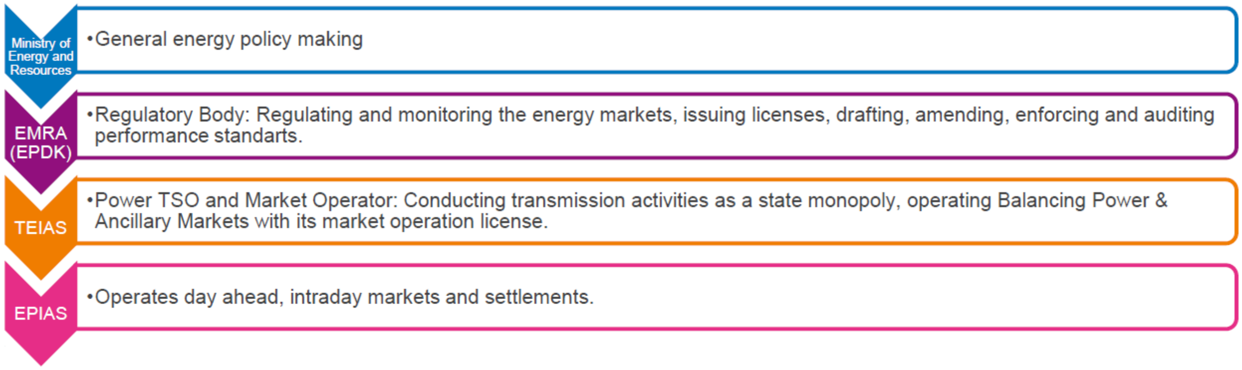

Figure 29 Key players of Turkish electricity market

i. Spot Markets

The day ahead market and the intra day market are the two electricity spot markets operated by EPİAŞ. Participation in the spot markets is not obligatory for market players Market participants have to sign the Day Ahead Market Participation Agreement and deposit the required guarantee.

Market participants can offer their bids including price and quantity to buy or sell electricity from the day ahead market for each hour of the following day.The market clearing price (DAMP, PTF in Turkish) and the traded volume are determined for each hour through matching the bids of buyers and sellers. After the day ahead market closes, participants have the option of supplying their needs through the intra day market.

The main difference between intra day and day ahead trading is the pricing of the markets:

The intra day market is a continuous market where orders will be immediately executed given that there is a matching offer in the opposite direction. Due to its nature, prices fluctuate throughout the day and the day ahead market determines a uniform market price and clearing volume for all transactions for each hour of the next day.

ii. Power Balancing Markets

The balancing power market is a market operated by TEİAS, the transmission system operator (TSO), where the buying and selling of reserve capacity, obtained through changes in output power that can be realized within fifteen minutes, takes place in order to balance the real-time supply and demand. The operation and management are carried out in real time via Milli yük tevzi merkezi (MYTM) affiliated to TEİAŞ.

Participation of market participants, which are balancing units, is obligatory. Figure 30 simply shows the balancing instructions. Balancing Units;

- Production plants capable of loading or de-loading at least 10 MW within 15 minutes.(Canal, river, type hydroelectric power plants; wind, solar, wave, tide, cogeneration and geothermal power plants are exempt from balancing unit.er)

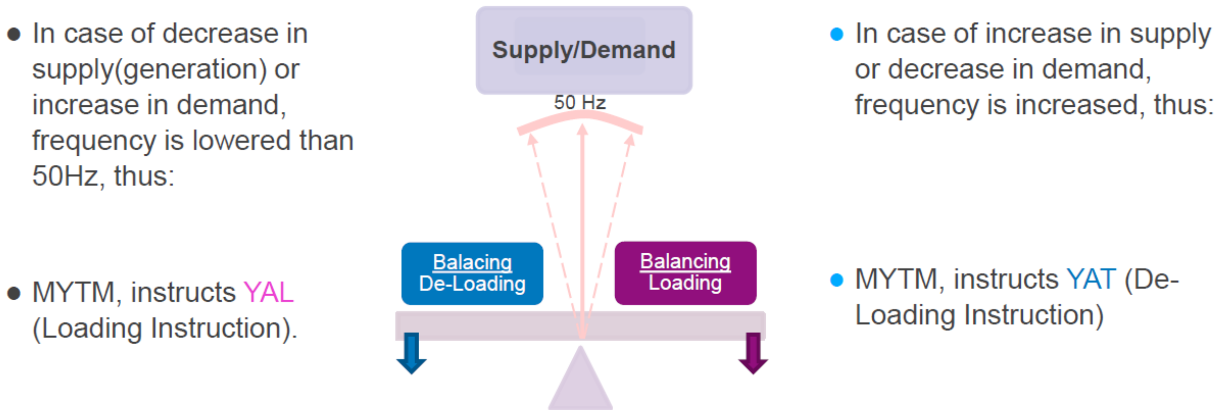

Figure 30 Balancing instructions (Orders)

Loading and de-loading bids are evaluated by TEİAS, and the system marginal price is found by the net volume and direction of TEIAS's orders. The market works on the marginal pricing principal, but TEIAS has the right to skip the bids and accept less price-suitable bids in a pay-as-bid manner based on location, need and the participants' prior actions.

iii. Power Ancillary Market

This market is primarily for frequency control and includes Primary Frequency Control and Secondary Frequency Control. The main objective is to maintain the frequency of the TSO transmission grid at the level of 50 Hz.With the PFC, if a frequency deviation of ±0.2Hz occurs in the system frequency, the activation by the plant is reacted by increasing or decreasing the active output power via the speed regulator in seconds. The secondary control is usually performed in an automatic way, by all the generators that are subject to this regulation, through specific "set-point" sent by a central controller.

As a summary, Daily market operations in Turkish electricity market can be seen in Figure 31.

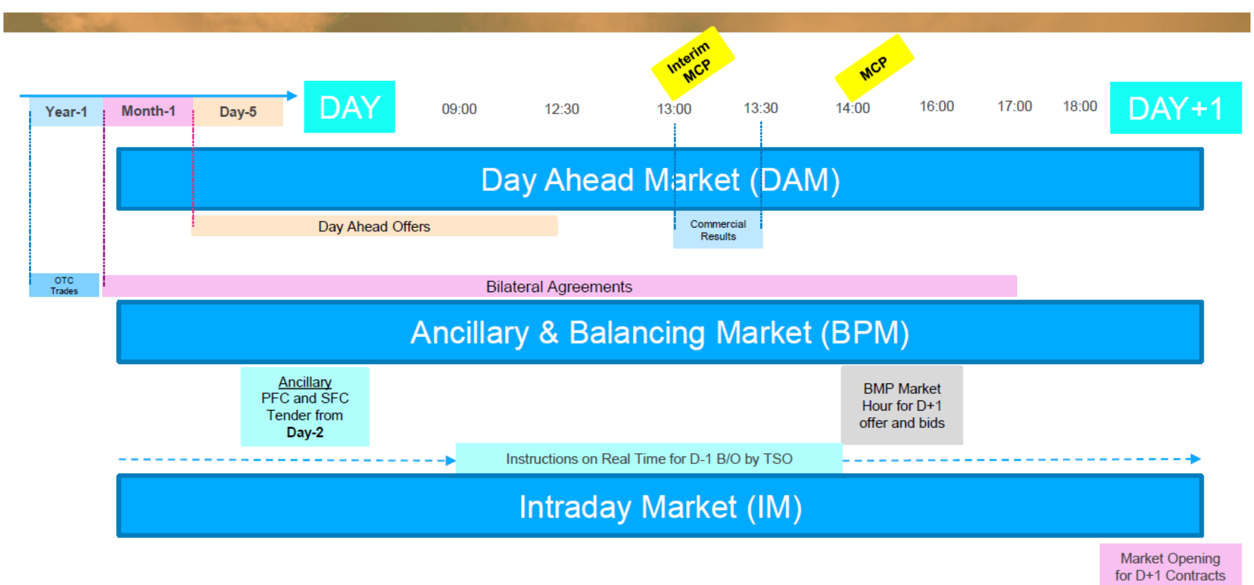

Figure 31 Daily power markets timeline

3.1.2 Flexibility services in the current Turkish electricity market

Currently there is no active flexibility market in Turkish electricity sector. Also demand side management is not applied in the Turkish market, and the implementation of such a scheme is not expected in the near future. Energy markets (EPIAS) are not yet open to demand-side participation; consumers can only participate in markets with production or supply licenses.

In Turkey, there is currently no flexibility market mechanism or specific regulation in place at the distribution grid level to enable congestion management. However, discussions are underway regarding the flexibility opportunities that distribution companies will have with the rapid increase of distributed generation sources and electric vehicles in the coming years. Many governmental institutions and research institutes are conducting studies in this regard. The aim for these relevant studies is to contribute to the future regulations that will be established.

It is known that demand-side participation applications, especially demonstrated through test studies in OEDAS's FlexiGrid project, will gain importance in the near future. Demand-side participation is one of the most cost-effective methods for increasing system flexibility. The use of demand-side participation applications is emphasized as an important policy objective for the Turkish energy market in many official strategic documents. It is included as a policy objective in works such as the "I. National Energy Efficiency Action Plan" published in 2017, the "2019-2023 Strategic Plan" published by the Ministry of Energy and Natural Resources, the "11th Development Plan 2019-2023," and the "2020 Annual Presidential Program" (T.C Presidency of Strategy and Budget, 2019).

In addition, relevant issues and opportunities have been examined through many R&D and strategy development projects supported by EPDK (Energy Market Regulatory Authority of Turkey). Despite the plans mentioned above for its dissemination, demand-side participation is currently not widely used in Turkey. The current status of demand-side participation in Turkey is summarized in Table 36.

Table 36 Current situation of demand side participation in Turkey (Shura)

Market	Service	Demand Side Response	Demand Side Direct Participation	Aggregator
Ancillary Services	Primary Frequency Control	No	No	No
	Secondary Frequency Control	No	No	No
	Instant Demand Control	Yes	Yes	No
Power Balancing	Energy	Yes	No	No
Day-ahead	Energy	Yes	No	No
Intraday	Energy	Yes	No	No

In addition, the Shura Energy Transition Center, which is conducting studies related to the decarbonization of the energy sector in Turkey, provided recommendations in its report published in 2022 regarding the steps to be taken to enhance flexibility in electricity systems. These recommendations offer a comprehensive assessment as they cover both regulatory requirements and decarbonization goals. A summary table of the recommendations can be seen in Table 37.

Table 37 Key options for enhancing flexibility and steps to be taken (Shura)

Flexibility Options	Recommendations: Positive changes in Market Architecture and increasing of market liberalization	Removing of the Fossil Fuel Subsidies	Comprehensive Road Plan to Achieve Renewable Energy and Decarbonization Goals	Legislation and Regulatory Framework	R&D and Infrastructure improvements	Additional Financial Incentives
Increasing Flexibility Through Market Architecture	X	X				
Energy Storage	X	X	X	X	X	X
Green Hydrogen	X	X	X	X	X	X
Demand Side Participation	X		X	X		
Electric Vehicles	X		X		X	
Digitalization and Smart Grids	X		X	X		

3.1.3. Market compatibility and flexibility potential of the tested assets: V2G, EV chargers

There are several different solutions for flexibility services that can be applied according to the need of the grid. Sperstad et al. (2020) stated that the flexibility services can be placed on two side of the grid such as grid side and supply/demand side. The same study classifies flexible resources into these three groups.

- Demand Response (DR) which includes load-based resources
- Energy Storage Systems (ESS)
- EV that covers mobile energy systems such as electrical vehicles

In this section of the study, flexibility potential of battery storage system and EVs will be investigated from DSOs perspective.

i. Energy Storage:

Energy storage facilities can potentially be used in the following application areas within the electricity market:

- Frequency control
- Congestion management
- Arbitrage

The following usage of storage systems for the grid can be summarized, according to the paper of the European Federation of Local and Regional Energy Companies.

- Energy storage systems (ESS) can be used as additional capacity for the grid when the demand reached its peak points.
- ESS can be used for preventing power quality issues that RES caused. Otherwise, increasing RES integration can cause injection of higher voltage level to the grid and this can cause electricity outages.
- Using of ESS for grid reinforcement can provide increase of quality and security of the grid.

- ESS also can be used for reactive power balancing applications.
- Peak shifting can be used for moving the peak load to lower load periods to avoid grid problems.

Looking at the developments in Turkey, the Energy Market Regulatory Authority (EPDK) published the Electricity Storage Regulation in its final form in May 2021. The regulation, which was initially released as a draft in January 2019, establishes a framework of rules for the use of battery storage systems in the market.

Storage units are able to sell electricity to the spot markets within the current regulations. However, under the existing legislation, the electricity that is withdrawn from the grid, stored, and then sold back to the grid is not evaluated within the framework of fixed purchase guarantees enjoyed by the relevant generation units. Additionally, storage facilities with a capacity exceeding 2 MW, which have a supply license and are installed independently, can participate in the Balancing Power Market and provide ancillary services, if they meet the necessary requirements. However, this situation does not apply to battery storage systems integrated with production or consumption facilities.

Additionally, within the current regulations, DSOs are allowed to commission storage facilities, provided they demonstrate that these storage investments are less costly than grid investments.

ii. Electric vehicles and smart charging:

Electric vehicles are important for increasing the flexibility of the electrical system. The charging times and durations of electric vehicles will have a significant impact on the hourly electricity load profiles throughout the day. Aggregating and clustering this demand will result in the provision of cheaper ancillary services and shifting of the load from peak hours to non-peak hours.

With the increasing usage of EVs, the electricity demand is rising day by day and causing electricity supply issues but also providing new opportunities to the electricity market. Since each EV has a battery, it has been realized that these batteries can be used as alternative storage solutions. Thus, a new flexibility service has emerged.

EVs provide various potentials for different participants of electricity services. This section of the study is focused on the potentials for the DSOs. Gonzalez et al. have divided flexibility potentials of EVs for flexibility services into the following four groups for DSOs in their research. [9].

- Local congestion management
- Voltage regulation
- Phase balancing
- Peak shaving / Valley filling

For applying these methods, management systems need to be used. Usually, information about EVs that are connected to charging stations needs to be collected first. Then, according to the load, charging durations of EVs need to be managed. **Smart charging**

Electric vehicles and EV charging stations, whose share is rapidly increasing, create a large and hourly unbalanced load profile in the electrical system. An uncontrolled approach to charging stations can severely damage the functioning of the electricity distribution system and cause electricity costs to rise. By foreseeing these negatives, it is necessary to analyze, manage, and plan the integration of additional load demand, which will increase further in the upcoming years, to minimize these negative effects.

The smart charging concept creates effective solutions for the benefit of both the grid and electric vehicle users, as well as new business models. In particular, the drivers habit of charging EVs during peak hours can lead to sudden increases in electricity demand. Therefore, incentives can be implemented to change the charging habits of drivers in public places, workplaces, or homes to encourage a charging hours shift.

These incentives require the implementation of dynamic multi-time tariffs and the adaptation of certain regulations in the electricity market to the EV smart charging concept. Currently, there is no legislation in Turkey's electricity market for the electric vehicle smart charging concept. In the coming years, with the increase of smart charging applications and the demand side taking an active role in the market and network, it will be imperative for distribution and transmission operators as well as policymakers to take action to keep the system operational. These future actions and regulations will pave the way forward for applications such as V2G, P2P, and energy storage systems, which could offer flexible solutions and bring benefits to the entire electrical system.

When considering the situation in Turkey, it can be observed that the initial regulation pertaining to the operation of electric vehicle charging stations was issued in April 2022. This regulation mainly encompasses rules concerning the specificities of charging station operations. However, there is currently a lack of regulations specifically formulated for evaluating the potential flexibility of electric vehicles or defining the CPO-DSO relationship in a clear and comprehensive manner.

3.2 Swiss pilot site

3.2.1 Swiss electricity market: Current situation, regulation, and legislation

In Switzerland, the functioning of the market is generally identical to the European market. The following markets are distinguished:

- The futures market for early coverage of supply needs and for annual or seasonal optimization of flexible production assets.
- The Day-Ahead market for forecasting the balance between production and consumption for the next day.
- The intraday market for very short-term balancing.
- The balancing market to ensure network stability and security with services provided by flexible assets.

The futures markets follow bilateral and over-the-counter contract conditions, while the Day-Ahead and Intra-day markets follow the Spot market. For the balancing market, there are specific conditions to be met, particularly in terms of quantity, duration, and deadlines. More information regarding the conditions can be found on the Swissgrid website, the Switzerland TSO. Prices generally follow market prices and the type of activated balancing asset.

A particularity of Switzerland is that only customers with an annual consumption exceeding 100 MWh are free to choose their energy supplier.

3.2.2 Flexibility services in the current Swiss electricity market

A project to revise the law on electricity supply is currently under consultation. In this project, electrical flexibility is regulated for the first time, granting the holder of flexibility the right to ownership and the freedom to offer their services. The project provides incentives for the development of flexibility markets and encourages new business models such as aggregators and virtual power plants. Several projects are already underway in Switzerland to develop these new services, including Quartierstrom [1]and V2X[2]. Flexigrid is also part of these projects to contribute its expertise in these new business models.

In Switzerland, electrical flexibility can be monetized through various markets. The most functional market currently is the Ancillary services (SDL) market, but participation conditions need to be met, which is often the case for large-scale flexibility sources. However, monetizing dispersed flexibility sources requires aggregation. This new role in the flexibility value chain already exists in Switzerland with solution providers like tiko[3], as well as producers and distributors like Alpiq and Axpo, but further regulation is still needed.

Monetizing flexibility for congestion resolution or power reduction is not yet widespread in Switzerland. However, this valuation is likely to develop in the coming years with the growth of decentralized production and the electrification of domestic loads. This will require the development of dynamic pricing models or local flexibility marketplaces. The demonstration site in Sion allows for the development and testing of this new business model of flexibility exchange through a flexibility market.

3.2.3 Market compatibility and flexibility potential of the tested assets: Batteries, HPs, P2G

A grouping of flexible assets can participate in the balancing market as long as it has been prequalified and has signed a framework contract with Swissgrid. The technical requirements[4] vary depending on the type of balancing it participates in (primary, secondary, or tertiary). Generally, offer intervals can range from 1 MW to 100 MW, and the activation duration can be between 15 minutes and 60 minutes. The response time can vary from a few seconds to 15 minutes. Batteries are well-suited for this kind of market.

Regarding the use of flexibility to reduce the balancing energy of a balancing group, any type of asset can be used as long as the energy constraints are met. Aggregating different assets also helps dilute abnormal behaviors that may occur for certain assets, such as heat pumps. However, a significant amount of flexibility on the order of MW is required to have a tangible effect on balancing energy. The flexibility from the Energypolis buildings is currently too low to have a real impact on the balancing group. It is necessary to aggregate additional flexibility to reach an interesting critical quantity.

[1] https://quartier-strom.ch/
[2] https://sun2wheel.com/en/blog/v2x-suisse-the-mega-project-of-sector-coupling/
[3] https://tiko.energy/
[4] https://www.swissgrid.ch/fr/home/customers/topics/ancillary-services/prequalification.html

4. Benefits and drawbacks of flexibility

4.1 DSO side

4.1.1 Benefits

The studies conducted within the scope of OEDAS demo, demonstrate the technical benefits of flexible resources such as distributed generation sources and electric vehicles in preventing DSO grid congestion. In the near future, with the increasing number of these assets, flexibility will be a necessary option for DSOs to manage local congestion issues in their power distribution grids. Particularly, activating demand side participation through various incentives and dynamic tariffs that can encourage end-users to enable DSOs to utilize these assets as a flexibility option.

Within the scope of the OEDAS demonstration, it has been shown that flexibility can be obtained from electric vehicles and battery storage systems in terms of congestion management. Due to the low electrical capacity of the used assets in demo, it is not easy to demonstrate their financial benefit to DSOs in terms of investment deferral using real data. However, with the method presented in the OEDAS case, it is possible to reduce potential peak loads on electrical infrastructure by managing a larger number of assets across a wider geographical area. This approach can help prevent additional investments in transformers and power lines on distribution grids.

The main benefits of flexibility options for DSOs are generally listed as follows, including some of the benefits evaluated within the scope of the OEDAS demonstration.

- **Enhanced Grid Stability:** Grid flexibility allows DSOs to manage the intermittent nature of renewable energy sources, such as solar and wind power. By dynamically balancing supply and demand, DSOs can stabilize the grid, ensuring a reliable and consistent power supply.

- **Efficient Energy Management:** Flexibility enables DSOs to optimize energy flows within the distribution grid. As seen in the OEDAS demonstration, energy management of flexible assets allows the provision of grid services to the DSOs and enables the provision of flexibility.

- **Demand Response and Load Balancing:** Flexibility allows DSOs to incentivize consumers to adjust their electricity consumption patterns based on grid conditions. By implementing demand response programs, DSOs can encourage consumers to shift their electricity usage to off-peak hours, reduce their consumption during periods of high demand or discharge energy from their assets (from batteries or EVs) when there is a flexibility request posted by a DSO. This load balancing helps in avoiding grid overloads and reduces the need for costly grid infrastructure upgrades. As mentioned before, this is the main objective of the OEDAS demonstration activities.

- **Voltage and Power Quality Management:** Grid flexibility helps DSOs manage voltage levels and power quality within the distribution network. By actively monitoring and controlling voltage, DSOs can maintain optimal conditions, reduce losses, and ensure the quality of power supplied to consumers.

- **Improved Asset Utilization:** By optimizing the use of existing grid assets, such as transformers, cables, and substations, grid flexibility enables DSOs to postpone or eliminate the need for expensive infrastructure upgrades. This leads to cost savings and more efficient use of resources.

- **Facilitating Electric Vehicle Integration**: The growing adoption of EVs poses new challenges for DSOs. Grid flexibility allows for the effective integration of EV charging infrastructure, enabling DSOs to manage the additional load and mitigate potential grid congestion issues.

- **Support for Energy Market Integration:** Grid flexibility can facilitate the integration of local energy markets and peer-to-peer energy trading. By enabling real-time information exchange and dynamic pricing mechanisms, DSOs can create an environment where consumers and prosumers (those who both consume and produce energy) can participate actively in the energy market, promoting energy efficiency and local grid resilience.

Overall, grid flexibility empowers DSOs to operate the distribution grid more efficiently, accommodate the increasing penetration of renewable energy sources and DERs, and enables the transition to a more sustainable, decentralized, and customer-centric energy system.

Here, it may be beneficial to highlight electric vehicles as a separate aspect, which is a key flexible asset of the Turkish demo studies. EVs can play several roles in helping DSOs reduce grid investments. Here are some key roles of EVs in this regard:

- **Vehicle-to-Grid (V2G) Technology:** EVs equipped with V2G technology can provide bi-directional energy flows, allowing them to not only consume energy from the grid but also return excess energy back to the grid. By utilizing V2G capabilities, DSOs can leverage EV batteries as distributed energy storage systems, reducing the need for additional grid infrastructure investments. During periods of peak demand or grid congestion, EVs can discharge stored energy back to the grid, providing valuable grid support and reducing strain on the distribution network.

- **Flexibility Demand and Load Management:** EV charging patterns can be managed to optimize their impact on the grid. By implementing smart charging strategies and time-of-use pricing, DSOs can incentivize EV owners to charge their vehicles during off-peak hours or when grid demand is low. This helps balance the load on the grid, minimize the need for additional peak capacity, and reduce congestion in specific areas, thus deferring grid investments.

- **Grid Services from EV Fleets:** Large-scale deployment of EVs, particularly in fleet operations such as public transportation or delivery services, presents opportunities for DSOs. By aggregating and controlling the charging and discharging behavior of EV fleets, DSOs can utilize them to provide grid services. These services may include frequency regulation, voltage support, or peak shaving. By leveraging the flexibility of EV fleets, DSOs can optimize grid operations and minimize the need for grid infrastructure upgrades.

- **Grid Planning and Asset Management:** The growing adoption of EVs provides valuable data for grid planning and asset management. DSOs can use EV adoption forecasts and charging behavior data to identify potential grid bottlenecks or areas where infrastructure upgrades may be required. By accurately predicting EV growth patterns, DSOs can better plan for future investments, optimize grid design, and ensure that infrastructure expansion aligns with the anticipated increase in EV charging demand.

Overall, EVs offer DSOs opportunities to optimize grid operations, manage load patterns, provide grid services, and leverage their batteries for grid support. By integrating EVs effectively into the grid ecosystem, DSOs can defer or reduce investments in grid i/nfrastructure, resulting in cost savings and more efficient grid management.

4.1.2 Risks and Drawbacks

While grid flexibility brings many benefits, there are also certain risks associated with its implementation. Here are some key risks of grid flexibility:

- **Grid Stability and Reliability:**

Introducing flexibility measures that actively manage electricity flows, demand response, and distributed energy resources (DERs) can introduce complexities to the grid. If not properly coordinated and controlled, these measures may increase the risk of grid instability or reliability issues. Sudden fluctuations in electricity supply or demand, improper voltage control, or inadequate coordination of grid assets can lead to voltage violations, frequency deviations, and grid instability.

- **Asset Availability:**

For DSOs, it is crucial to receive the desired level of support during the requested time interval in terms of flexibility. In this regard, ensuring excellent coordination between the DSO and the FSP, as well as indirectly between the DSO and the asset, is essential.

Furthermore, environmental and weather conditions can affect the flexibility potential of FSP assets. It is preferable for the batteries to continue their operations within optimal operating temperatures. Especially in extreme hot or cold weather conditions, the FSP may not be able to provide support. This situation poses a risk factor that can impact the DSO's flexibility acquisition process. The same applies to EV batteries. Particularly in cold weather, EVs with reduced range and available capacity may not be able to provide flexibility to the DSO at full capacity in the context of V2G cases. It is crucial to carefully consider and evaluate these limitations between the FSP and DSO during operations.

The charge/discharge capacity of the asset directly affects the flexibility trading process between the FSP and DSO. Throughout the service period, the maximum and minimum capacities that the asset can provide should be well defined and communicated to the DSO. Otherwise, situations may arise where flexibility delivery exceeds or falls short of the requested flexibility value. Particularly when considering the minimum allowed SoC values of the battery, poor capacity planning can even lead to the asset being out of operation during the flexibility delivery process and deviating the battery from its normal operational mode.

To minimize the mentioned risk factors, the FSP should have management platforms that enable highly advanced monitoring and control of assets. Subsequently, establishing a seamless communication channel between the DSO and FSP before and during the flexibility delivery process, and ensuring the availability of the asset, are crucial for the optimal management of the process.

- **Lifetime of Assets:**

This risk parameter, which needs to be especially evaluated by the FSP, can hinder the ability of DSOs to acquire flexibility in certain cases. When assessing battery cycles for stationary battery and V2G applications, each discharge operation has a direct impact on the battery's lifetime. When considered by the FSP, this situation can create a barrier to activating demand-side management in intervals where the DSO can dynamically request flexibility. There are ongoing discussions regarding the effects of discharging from vehicle batteries in V2G applications on battery life. This situation can negatively impact the willingness of V2G users to provide services to the grid.

- **Potential negative effects of V2G:**

V2G technology, which has not yet gained full acceptance, holds a significant position in the conducted demonstration study. As the number of V2G installations increases in the future, V2G offers substantial flexibility potential, but it also brings along certain risks in the process of providing flexibility.

- **Battery Degradation:** The frequent charging and discharging cycles associated with V2G operations can accelerate battery degradation. While EV batteries are designed to withstand thousands of cycles, the additional stress from bidirectional energy flows and more frequent charge/discharge events can contribute to reduced battery lifespan over time. This may result in decreased overall battery capacity and performance.

- **Increased Cycling and State-of-Charge (SOC) Range:** V2G operations involve utilizing a broader range of the battery's state-of-charge, meaning the battery is discharged to lower levels and charged to higher levels more frequently. This extended SOC range can lead to increased wear on the battery cells, impacting their longevity and overall energy storage capabilities.

- **Temperature Fluctuations:** V2G operations can expose EV batteries to temperature fluctuations. When using the battery for grid services, it may experience more rapid and extreme temperature changes than during typical vehicle usage. Temperature extremes can impact battery health and contribute to accelerated degradation.

- **Charging Infrastructure Compatibility:** V2G requires specific charging infrastructure that supports bidirectional energy flow. Not all charging stations or EV models are currently compatible with V2G technology. Limited availability of V2G-capable charging infrastructure may restrict widespread adoption and utilization of V2G, reducing its potential benefits.

- **Warranty Considerations:** The use of V2G technology may affect the warranty coverage of EV batteries. The additional stress on batteries from bidirectional energy flows and increased cycling may not align with the warranty terms provided by the vehicle manufacturer. It is important for EV owners to carefully review their warranty agreements to understand any potential limitations or exclusions related to V2G usage.

To mitigate these negative effects, it is crucial to implement proper battery management systems and protocols when deploying V2G technology. These systems should monitor battery health, manage charging and discharging cycles, and optimize battery usage to minimize degradation. Additionally, ongoing research and development efforts focus on improving battery technologies, enhancing their longevity, and addressing the challenges associated with V2G operations.

It's worth noting that the extent of the negative effects on car batteries depends on various factors, including the battery chemistry, charging patterns, depth of discharge, temperature management, and the specific V2G implementation. Advancements in battery technology, improved battery management algorithms, and careful operational strategies can help mitigate these negative effects and ensure the long-term viability of V2G systems.

Also, from the perspective of DSOs, if V2G vehicle batteries are not managed optimally, there is potential for creating certain problems.

- **Grid Instability and Voltage Fluctuations:** The bidirectional power flow introduced by V2G operations can create challenges for grid stability and voltage control, if it is not managed in a smart manner. Rapid fluctuations in power injection and withdrawal from EV batteries can impact grid voltage levels, leading to voltage variations and potential instability. DSOs need to ensure that the integration of V2G systems does not compromise the overall grid reliability and quality of supply.
- **Grid Planning and Asset Management:** The implementation of V2G technology introduces additional complexities to grid planning and asset management for DSOs. The dynamic nature of V2G operations, which rely on the availability and willingness of EV owners to participate, can introduce uncertainties in load forecasting and grid capacity planning. DSOs may need to revise their grid planning strategies to accommodate the variability and unpredictability of V2G resources.

- **Control and communication requirements:**

When evaluating the process from both the DSO and FSP perspectives, controlling different assets together is a challenging process. Poorly designed structures can also entail operational risks at this point. It is essential for management platforms to support different communication protocols and provide uninterrupted real-time communication with the equipment to effectively monitor and control the assets in an enhanced manner. Therefore, a well-designed framework should be established from the beginning to prevent any risks. Particularly in cases where multiple assets need to respond to a single flexibility request from the DSO, this control and monitoring structure becomes even more important. Using a shared monitoring and management platform with different dashboards can reduce risks and also enhance communication between the FSP and DSO. This approach will provide advantages to both parties in terms of managing the flexibility delivery process

- **Activating demand side participation:**

As demonstrated in the test cases, demand-side participation is essential for DSOs to perform congestion management with the relevant assets. Therefore, it is necessary to convince and incentivize the demand side to participate in the process and contribute. Factors such as tariff structures that do not allow the FSP to generate revenue and inadequate incentives can pose a risk to the involvement of the end users/FSPs. Similarly, the absence of tools for end users to convey their preferences and manage the process, poorly designed communication platforms, and other related issues can lead to a decrease in the willingness of FSPs and electric vehicle users to participate in the process. This situation can be considered as an obstacle to DSOs' acquisition of flexibility.

- **Cybersecurity Vulnerabilities:**

The increased reliance on advanced grid monitoring and control systems, communication networks, and data exchange in a flexible grid introduces potential cybersecurity vulnerabilities. A cyberattack on grid infrastructure or control systems can disrupt operations, compromise grid security, and lead to significant disruptions in the electricity supply. Robust cybersecurity measures and protocols are essential to mitigate these risks.

- **Technical Integration Challenges:**

Integrating new technologies and flexible resources into the grid can present technical challenges. Compatibility issues between different types of grid assets, communication protocols, and control systems can arise, leading to interoperability problems and hindered coordination. Ensuring seamless integration and interoperability between various grid elements and flexibility measures requires careful planning, standardization, and technical expertise.

- **Data Management and Privacy:**

Grid flexibility relies on the collection and analysis of vast amounts of data, including consumer energy consumption patterns, grid performance data, and DER integration information. Managing and securing this data while respecting privacy regulations is crucial. Inadequate data management practices, data breaches, or privacy violations can erode consumer trust and compromise the successful implementation of flexibility measures.

- **Transition and Adaptation Costs:**

Implementing flexibility measures often requires upfront investments in technologies, infrastructure upgrades, and system redesign. The transition from traditional grid operation to a more flexible and dynamic system may involve significant costs, including hardware installations, software development, training, and operational adjustments. Proper cost-benefit analysis and long-term planning are necessary to ensure that the benefits outweigh the initial investment costs.

- **Market Design and Regulation:**

Flexibility implementation may require adjustments to market design and regulatory frameworks. The existing market structures and regulations may not be fully equipped to accommodate the active participation of flexible resources and demand response. Inadequate market rules, pricing mechanisms, or regulatory barriers can hinder the effective deployment of flexibility measures and limit their potential benefits.

As mentioned, the lack or insufficiency of regulations has the potential to create risks in the operation of flexibility trading. Especially, the absence of regulations that effectively govern the relationship between FSP and DSO to enable demand-side participation can impact these operations. Similarly, from the DSO's perspective, it is crucial to have a properly defined relationships between CPO, DSO, and end-users through regulations to manage the congestion management process effectively.

Addressing these risks requires careful planning, risk assessment, and the adoption of appropriate technological and regulatory measures. Collaboration between stakeholders, including grid operators, regulators, technology providers, and FSPs&end users is essential to effectively manage and mitigate the risks associated with grid flexibility.

4.2 FSP side

4.2.1 Benefits

FSP receives remuneration for providing planned flexibility within the requested timeframe, thereby assisting in grid balancing. Determining the appropriate remuneration pricing is crucial, and FSP should ensure fair compensation for the value it delivers. Several factors influence the determination of remuneration prices, including the type (renewable or non-renewable) and amount of flexibility provided, the frequency of flexibility provision, and prevailing market conditions.

In this regard, various options for remuneration prices, including the critical remuneration price that balances all costs and income associated with providing flexibility, must be carefully evaluated. This subject has been discussed in detail in (section 2.2.1 Flexibility Evaluation Method).

Moreover, it is essential to consider not only the remuneration amount but also other KPIs of flexibility test cases to provide a comprehensive evaluation. Therefore, this section presents the remuneration, along with the most significant economic and reliability KPIs of flexibility in all different test cases. This comprehensive analysis is provided in Table 3838.

Table 38 Comprehensive analysis of KPIs for various flexibility services.

Test cases		Reliability (%)			Operation Cost (ctCHF)	Critical Remuneration Price (ctCHF/kWh)	Remuneration (ctCHF)	Penalty (ctCHF)	Revenue (ctCHF)
Request	Assets	FDR	PFR	FAI					
Positive	Battery	0	100	100	362	14.35	189	0	-173
Positive	HP 19	0.32	99.68	98.33	189	6.02	258	0	+69
Negative	HP 19	0	100	100	182	6.02	269	0	+87
Positive	HP 23	6.92	93.08	85	162	6.02	302.0	5.80	+134.2
Negative	HP 23	9.16	90.84	100	128	6.02	188	7.80	+60
Positive	SOFC-300 W	7.71	92.29	99.16	12.12	56.64	2.48	0.067	-9.71
Positive	SOFC-6 kW	5.2	94.80	100	505.80	76.98	70	0.11	-435.11
Negative	SOEC-20 kW	3.31	96.69	100	200.4	9.23	126.19	0	- 74.21
Positive	Battery + HP_19	1.14	98.86	100	534	10.57	429.0	0	-105
Positive	HP_19 + HP_21 +HP_23	23.93	76.07	55	465.0	6.02	852.0	161	+226
Negative	HP_19 + HP_21 +HP_23	4.70	95.30	93.33	445.0	6.02	634.0	0	+189
Positive	HP_19+Battery +SOFC	1.15	98.85	98.33	1186.0	16.75	600	0	-586
Negative	HP_19+Battery +SOEC	1.24	98.76	98.33	220.0	7.68	251.0	0	+31.0

The critical remuneration price for different test cases is provided in Figure 32.

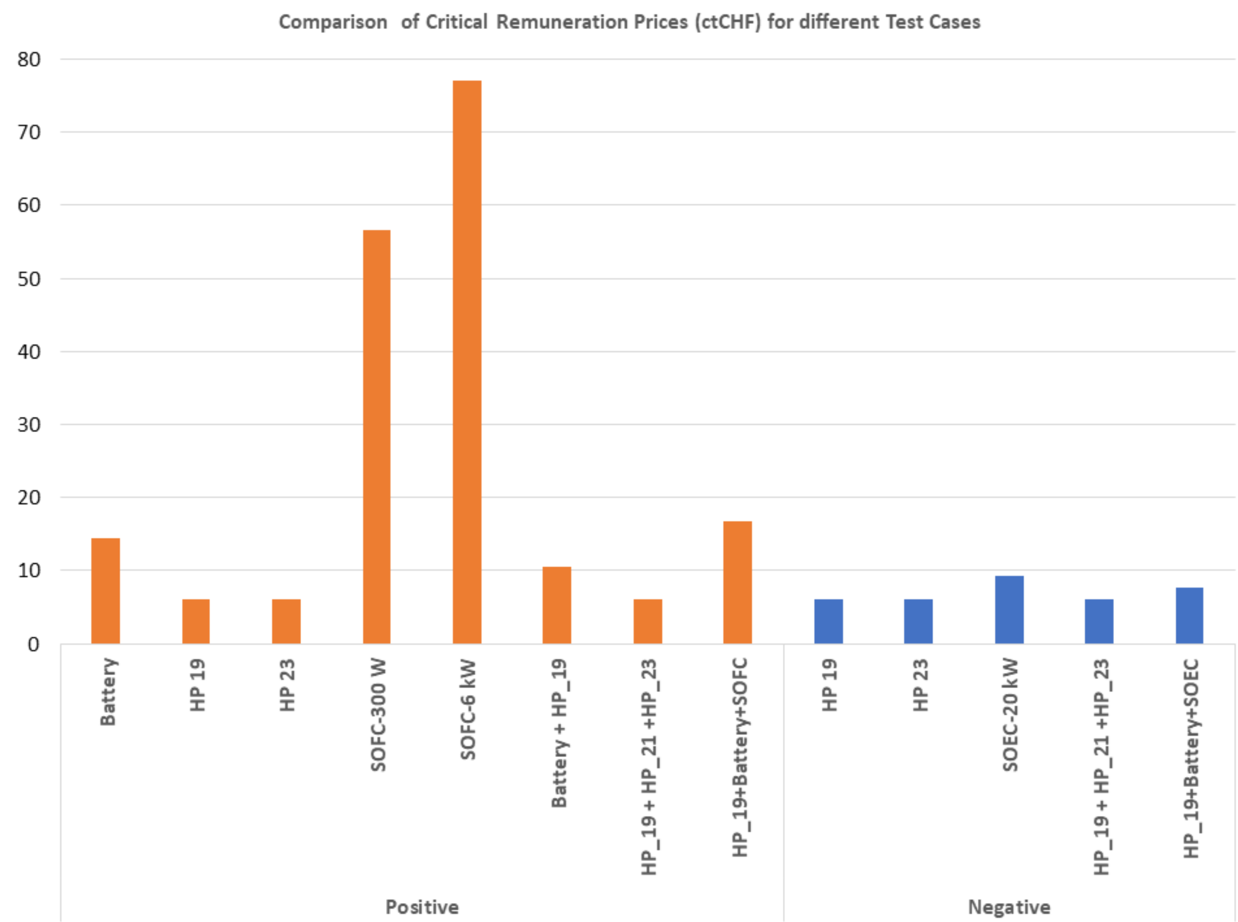

Figure 32 Comparison of critical remuneration prices for different flexibility services

As depicted in the above figure, the remuneration for P2G systems, particularly for the SOFC asset, is higher compared to other test cases. This indicates that when there is a positive request and the flexible asset used for providing flexibility is the SOFC, the associated remuneration cost must be higher compared to the remuneration for other assets. On the other hand, the integrated three HPs for providing flexibility demonstrate the minimum critical remuneration price.

From these evaluations, two important lessons can be drawn:

1. When multiple assets are involved in providing flexibility, the critical remuneration price tends to decrease compared to when only one asset is utilized. This economic justification is beneficial for both the FSP and OIKEN.
2. Generally, the critical remuneration price for negative requests is lower than that for positive requests. This suggests that there is greater economic viability for providing flexibility in cases of negative requests.

The comprehensive analysis of different KPIs for flexibility services is presented in *Figure 33* for positive flexible requests and *Figure 34* for negative flexible requests. The KPIs considered in the analysis include Predicted Flexibility Reliability (PFR), Operation Cost, Remuneration, and Revenue.

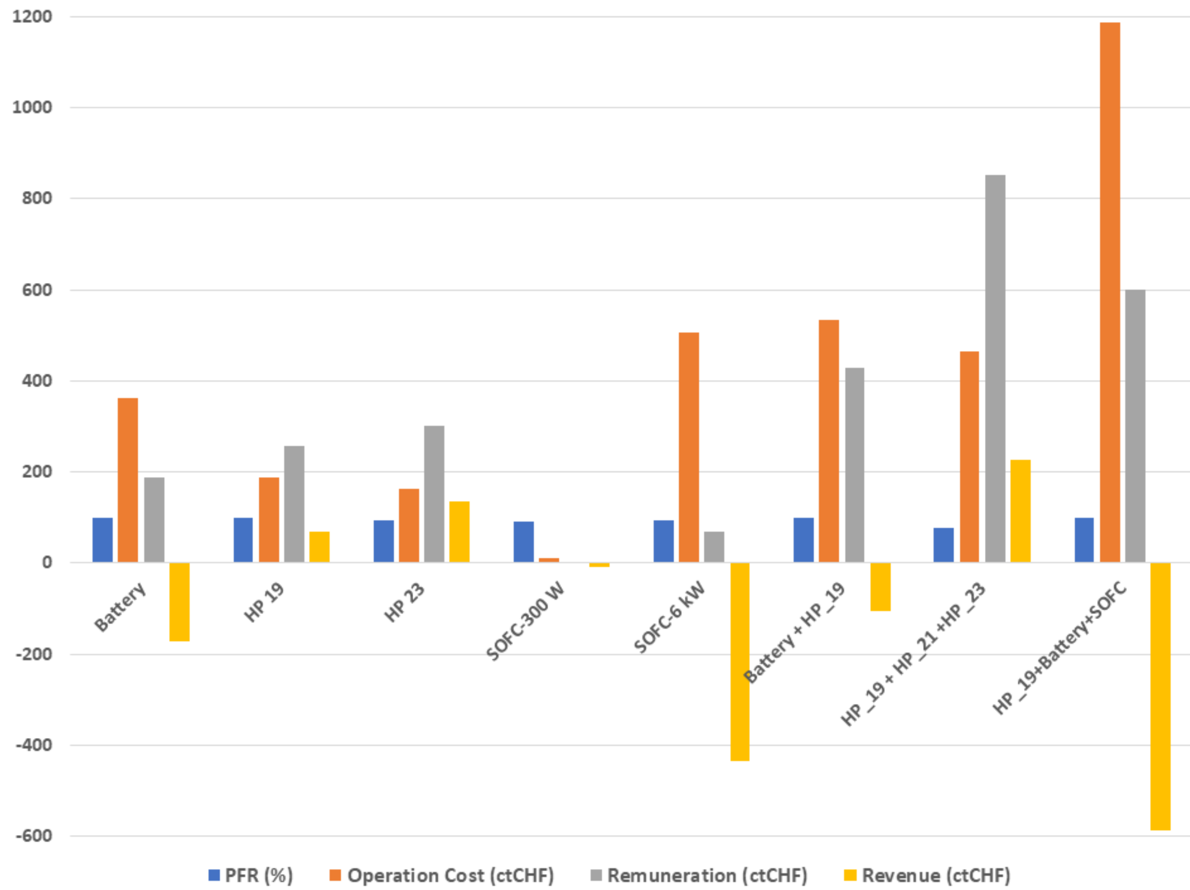

Figure 33 Comprehensive analysis of different KPIs) for flexibility services in positive requests

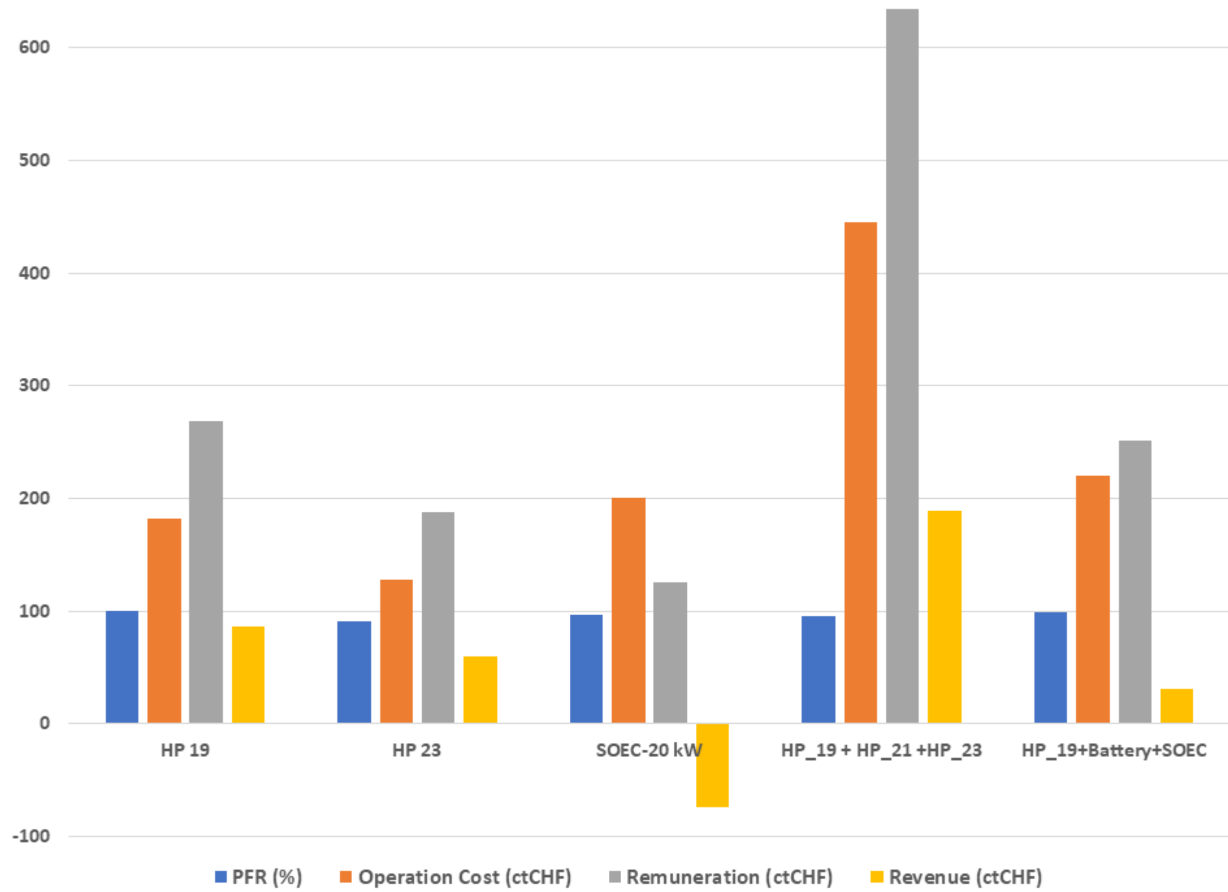

Figure 34 Comprehensive analysis of different KPIs for flexibility services in negative requests

From the two figures and the comprehensive evaluations, the following important lessons can be drawn:

1. In positive request cases with a single asset, the Heat Pump generates the highest revenue, indicating better economic justification compared to the SOFC, which has the lowest revenue. However, the HP also exhibits lower reliability compared to the SOFC and also compared to battery, which has the highest reliability index. This can be concluded that the HP offers better economic viability but lower reliability in flexibility operations.
2. In negative request cases, the HP demonstrates better economic justification with higher revenue, while the SOEC shows lower economic viability with negative revenue. Similar to positive request cases, the HP exhibits lower reliability compared to the SOEC, which has better reliability in flexibility operations.
3. When multiple assets are used, the economic justification tends to improve compared to individual assets providing flexibility alone. However, the reliability evaluation differs from the economic evaluation. The presence of a battery in the multiple assets helps compensate for the inefficiency of other assets such as the HP, resulting in an overall increase in the reliability index of the flexibility service. Conversely, when there is no battery in the multiple assets, the reliability of the service decreases due to the challenges of controlling different assets for providing flexibility. This is evident in the case of multiple HP assets, where the reliability index is reduced.

4. In general, negative request cases show better economic and reliability indices compared to positive request cases. This suggests that when FSP needs to consume more energy to provide flexibility, the flexibility services can be better managed from both economic and reliability perspectives.

4.2.2 Risks and drawbacks

The provision of flexibility by the Flexible Service Provider (FSP) can also come with potential risks that require careful consideration and management. Some of the risks that need to be addressed include the risk of overconsumption, availability, installation lifetime, challenging control the different assets, time consumption, operational complexity, and revenue uncertainty in flexibility services. In this section, we generally aim to define and evaluate these drawbacks and their relationship to the flexibility assets implemented by the FSP to provide flexibility. Furthermore, we will provide several suggestions for mitigating these risks.

- ***Potential overconsumption:***

In this section, we will explore the drawbacks of potential overconsumption from the viewpoint of FSPs. When FSP receives a negative request, it means that it needs to increase consumption for flexibility period. While this can be beneficial in some cases, it can also create potential drawbacks and risks for FSP, especially if it leads to overconsumption.

1- *Increased Energy Consumption and Unsustainability*: One of the main risks of overconsumption is the increase of energy consumption and energy loss and consequently, increase the cost of energy. When flexibility assets are activated to provide services, they may consume more energy than would be necessary under normal operation. In this case, overconsumption can result in a higher loss and higher carbon footprint, which may not align with sustainability goals and values. Additionally, if FSP increases consumption, it needs to purchase additional energy from the grid, which can affect its profitability and financial viability.

2- *Deviation from Optimal System Operation and Decreased Efficiency*: Operating flexibility assets for the purpose of providing flexibility can lead to a deviation from their optimal operation. For instance, when a heat pump is utilized to provide flexibility, it may not be operating in its most efficient mode. As a result, the coefficient of performance (COP) of the heat pump may decrease, resulting in energy losses. This reduced efficiency can have a negative impact on the overall performance of the energy system, leading to suboptimal energy utilization.

3- *Discomfort and Suboptimal Conditions*: Another drawback of providing flexibility from the FSP's perspective is the potential for discomfort and suboptimal conditions for end-users. For example, when a heat pump is employed to provide flexibility during periods where there is no real need for heating or cooling based on the inside and outside temperatures, it may lead to an increase in temperature, causing discomfort. This scenario can negatively affect the overall user experience and satisfaction with the energy system.

To enhance the comprehension of the overconsumption risk associated with flexibility from the FSP's perspective, we present Figure 35.

Among the flexibility assets available, the Heat Pump (HP) demonstrates a higher potential to overconsumption compared to other assets when employed for providing flexibility services. This concern is illustrated in Figure 35. This figure illustrates a negative request at 8 AM, indicating the need for increased energy consumption by the Flexible Service Provider (FSP) during this time. Without flexibility requirements, the HP operates optimally in its automatic mode, maintaining its rated COP (Coefficient of Performance). However, at 10 AM, the HP starts operating and consumes additional energy to fulfill the requested flexibility. This shift in the HP's optimal operating hour from 10 AM (optimal schedule) to 8 AM (flexibility time) results in a malfunction in efficient energy consumption of HP. As shown in this figure, a portion of the energy losses can be attributed to the HP's deviation from its optimal schedule. Another part of the losses is linked to the excess energy consumption and discomfort in indoor temperature that can arise when the HP operates at an inappropriate time. In summary, when the HP, serving as a flexibility asset, provides flexibility during periods when it is not necessary, it leads to overconsumption and discomfort, resulting in a loss of energy efficiency during the flexibility time.

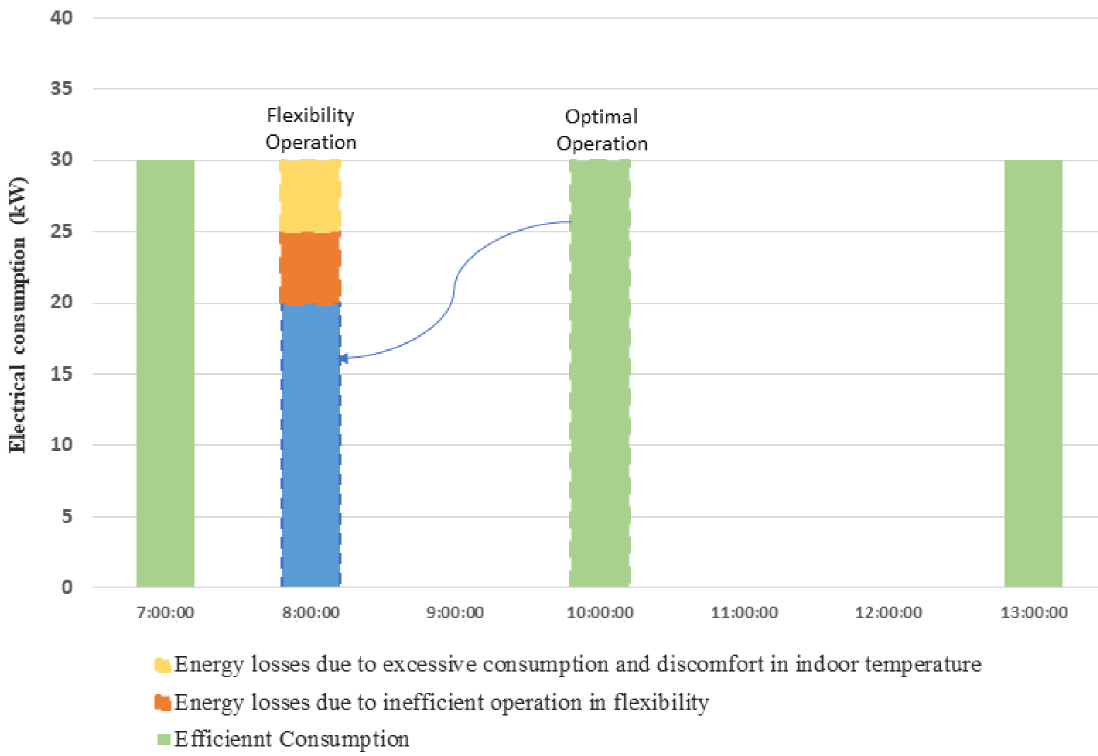

Figure 35 Overconsumption risk of Heat Pump (HP) as a flexibility asset

To mitigate the risks of potential overconsumption associated with providing flexibility, several measures can be taken:

- *Demand-side Management*: Implement demand-side management techniques to optimize energy usage in specific time horizon including flexibility period and reduce overall consumption. This can involve strategies such as load shifting, load shedding, and demand response programs. By timely managing the demand for energy and optimizing its use, FSP can reduce the risk of overconsumption and at the same time, ensure that it can respond to flexibility requests.

- *Flexibility Offer Planning*: Accurate flexibility offer forecasting plays a crucial role in mitigating overconsumption risks. By developing robust flexibility offer forecasting models, flexibility service providers can ensure that they operate within their safe and efficient limits considering the operational limits, condition of the assets and demand forecasting.

- *Advanced Control Systems*: Deploying advanced control systems that continuously monitor and optimize the performance of flexibility assets helps mitigate overconsumption risks. These systems can adjust the operation of assets in flexibility period, based on real-time energy demand and system efficiency metrics, ensuring optimal utilization, and reducing energy waste.

- *Backup and Energy Storage Integration:* to mitigate the risk of full capacity and inability to provide the requested flexibility, FSP needs to develop contingency plans and backup strategies, such as implementing additional energy storage capacity or diversifying its energy asset portfolio to ensure that it can meet the request for flexibility even under challenging conditions.

- ***Availability***

Availability is a crucial aspect of flexibility services provided by FSPs, and it comprises various factors, including reliability. Ensuring the availability of flexibility resources is essential to meet the flexibility requests. However, several challenges can impact availability from the FSP side. These challenges include:

1. Reliability: Reliability is a key performance indicator (KPI) for availability. It is a crucial factor for the availability of flexibility assets, such as battery systems, heat pumps, and power-to-gas systems. It refers to the ability of these assets to consistently deliver the required services without interruptions or failures. The reliability of flexibility assets can be influenced by various factors, including the age and condition of the assets, the effectiveness of maintenance practices, and the robustness of control systems.
2. Asset/Resource Constraints: The availability of flexibility services can be influenced by resource constraints associated with specific flexibility assets such as battery systems, heat pumps, and power-to-gas systems. One significant factor that affects the availability of heat pumps is the temperature. Heat pumps rely on the temperature of the surrounding environment to operate efficiently. In regions with extreme temperatures, such as very cold or very hot climates, the performance and availability of heat pumps may be limited. Additionally, capacity limitations, operational constraints, and weather conditions can also impact the availability of flexibility resources. For example, a limited storage capacity of battery systems or intermittent availability of renewable energy sources can pose challenges to maintaining consistent availability of flexibility services.
3. Scheduling and Dispatching Challenges: Coordinating and optimizing the availability of different flexibility assets/resources can be complex. FSPs need to effectively schedule, and dispatch assets/resources based on flexibility requests and market conditions. Challenges can arise in terms of response times, competing demands for the same assets/resources (opportunity cost), and operational constraints that impact availability.
4. Technical Limitations: The technical capabilities of flexibility assets can impact their availability. Some assets may have inherent limitations, such as response times, operational constraints, or ramp-up times, which affect their ability to provide flexibility services on request.
5. Communication and Coordination: Effective communication and coordination between FSPs and other participants such as OIKEN are crucial for ensuring availability. Delays or inefficiencies in communication channels can hinder the timely delivery of flexibility services, impacting availability.

To gain a better understanding of flexibility reliability, two key reliability indexes, namely Predicted Flexibility Reliability (PFR) and Flexibility Availability Index (FAI), are depicted in Figure 36. The figure illustrates the reliability indexes across various flexibility services.

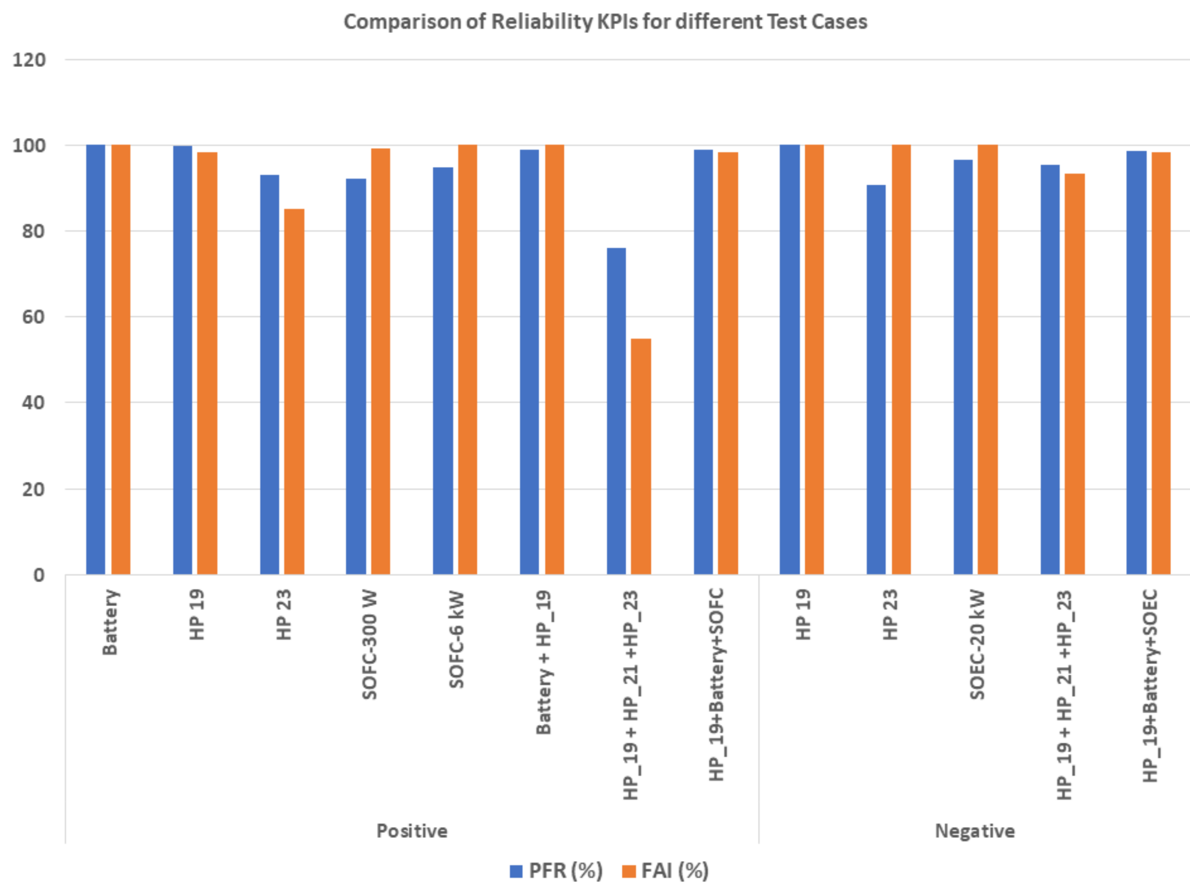

Figure 36 Comparison of reliability indexes for different flexibility services

As depicted in the figure above, the reliability index of the HP asset is lower compared to the other assets. This is particularly evident when multiple HP assets are involved in providing flexibility, as the control and coordination of these assets becomes more challenging, leading to a further decrease in reliability compared to other flexibility services.

To address the challenges and ensure availability and reliability, FSPs can consider the following strategies:

- Robust Maintenance Practices: Implementing proactive maintenance practices helps identify and address potential issues in flexibility assets before they impact availability. Regular maintenance, predictive maintenance, and condition monitoring can enhance reliability and minimize downtime.
- Diversification of Resource Portfolio: FSPs can diversify their resource portfolio by including a mix of different flexibility assets. Having a diverse resource portfolio helps mitigate availability risks and ensures a more reliable and consistent provision of flexibility services.
- Resilient Control Systems: Developing robust control systems that can manage and optimize the behaviour of flexibility resources improves reliability and availability. This includes real-time monitoring, fault detection, and rapid troubleshooting capabilities.

- Market Monitoring and Forecasting: Continuous monitoring of market conditions, demand patterns, and pricing mechanisms enables FSPs to anticipate and plan for availability requirements. Accurate demand forecasting helps optimize resource allocation and scheduling, improving availability.
- Collaboration and Partnerships: Building collaborative partnerships with aggregators, energy suppliers, and grid operators can enhance availability. By sharing resources, information, and expertise, FSPs can ensure a more reliable and robust provision of flexibility services.

By addressing these aspects and implementing appropriate strategies, FSPs can enhance the availability and reliability of flexibility services, meeting the flexibility requests effectively.

- ***Installations lifetime***

Asset Degradation and Reduced Lifespan: One significant drawback of providing flexibility services is the potential for accelerated asset degradation and a reduced lifespan of the installation. Flexibility assets, such as heat pumps, batteries, and power-to-gas systems, may experience increased wear and tear when operated for flexibility purposes. Flexibility can require the assets to operate at higher or lower capacity levels than they would under normal operating conditions or increase the operating cycles/hours of assets, which can result in increased degradation, reduced efficiency, and shortened lifetimes.

Furthermore, the operational requirements for flexibility provision may deviate from the optimal operating conditions of the assets. This deviation can further accelerate wear and energy losses. For instance, a heat pump operating outside its designed temperature range to provide flexibility may experience reduced efficiency and increased energy consumption, impacting its overall durability.

1- For example, in the case of a heat pump used for flexibility, the frequent start-stop cycles and extended operating hours may contribute to increased mechanical strain and component fatigue. As a result, the heat pump's efficiency may decline over time, leading to reduced performance and potentially requiring premature replacement.
2- Additionally, the frequency and depth of battery cycling required to provide flexibility services can cause degradation of the battery's performance over time, leading to a reduced lifespan. In addition, the temperature and state-of-charge (SoC) operating ranges that batteries must operate within to provide flexibility services can also impact their lifespan. To mitigate the impact of flexibility on battery lifespan, FSPs must control the battery scheduling as it is limited to work in the allowed operating SoC range.
3- Similarly, P2G systems, which convert electrical energy into hydrogen gas (SOEC) or vice versa (SOFC), require certain operating conditions to maintain their performance and lifespan. When P2G systems are operated for flexibility services, their operating conditions may deviate from their optimal range, which can lead to additional degradation (Electrode degradation, Impurities and degradation of catalyst, temperature cycling and water management), reduced efficiency and resulting in a reduced lifespan. For example, during periods of high electricity demand, P2G systems may be operated at maximum power output for extended periods, which can increase operating temperatures and cause thermal stress. This can lead to accelerated degradation of materials and components, which can ultimately result in reduced performance and shorter lifespan.

Different indexes can be introduced to quantify the extent of damage, such as performance or economic losses, experienced by each asset while providing flexibility services. One prominent index is the Levelized Cost of Energy (LCOE). The LCOE measures the economic loss incurred by each asset for every kWh of energy provided during the flexibility period. It considers the total cost of the asset over its lifetime and breaks it down to the cost per kWh (Section 2.2.1 Flexibility Evaluation Method). The LCOE serves as a valuable criterion for quantitatively assessing the drawback of asset lifetime in flexibility services. By considering both performance and economic factors, it provides a comprehensive measure of the impact on asset longevity. A higher LCOE indicates a greater loss incurred by the asset while providing flexibility, reflects potential decreases in performance and economic viability.

By utilizing the LCOE and similar metrics, flexibility service providers can evaluate and compare the effects of flexibility provision on asset lifetime across different assets. This quantitative assessment assists in making informed decisions regarding asset selection, maintenance strategies, and overall asset lifecycle management. The LCOE comparison for various flexibility assets, including Battery, Heat pumps, and P2G systems, is depicted in Figure 37. The LCOE values are calculated based on the specific characteristics of each asset when utilized for providing flexibility services.

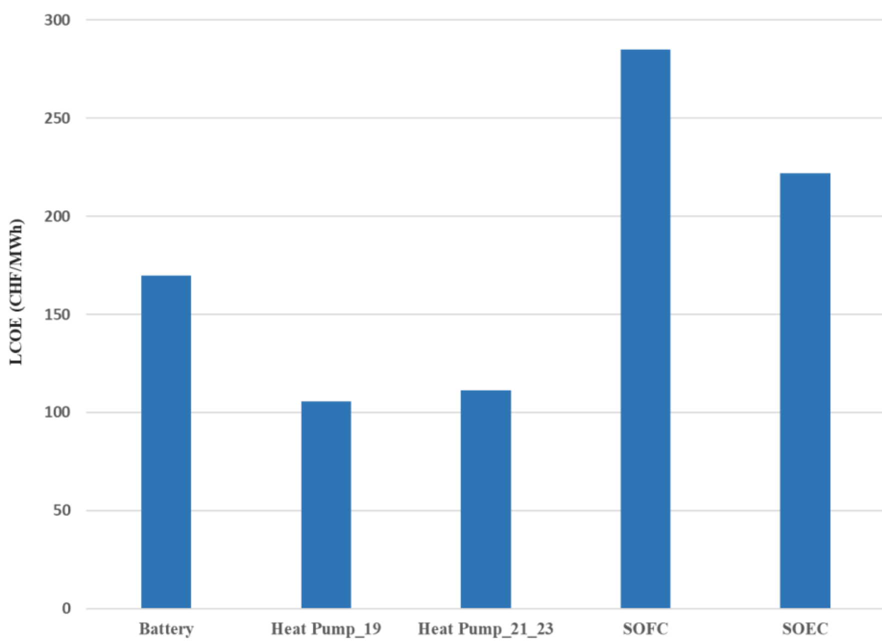

Figure 37 LCOE Comparison for Different Flexibility Assets

As depicted in the figure, the heat pump exhibits the lowest LCOE among the other flexibility assets. This finding suggests that the heat pump is the most cost-effective option for providing flexibility services. The lower LCOE indicates that the heat pump incurs relatively lower losses and costs per unit of energy provided during the flexibility period.

On the other hand, the P2G systems exhibit the highest LCOE among the flexibility assets, indicating that they have limited economic justification for participating in flexibility services. However, it is important to note that the economic assessment of assets for providing flexibility is just one aspect of a comprehensive evaluation. Other aspects need to be considered to provide a holistic assessment of flexibility assets.

To mitigate the risks of Installations lifetime:

- FSPs need to consider the impact of flexibility on the asset lifetime when planning its offer for determining the asset operation. Furthermore, FSPs also need to consider the impact of flexibility on the financial viability of their energy assets, considering the potential costs associated with maintenance, repair, and replacement. By optimizing the use of its energy assets and minimizing the impact of flexibility on their installation's lifetime, FSP can provide reliable and cost-effective flexibility while ensuring the long-term reliability and efficiency of its energy assets.

- For HPs, it is important to carefully design the control strategies to minimize the impact on their lifetime. This can include optimizing the frequency and duration of the setpoint changes, and avoiding extreme temperature conditions that may cause unnecessary stress on the HPs. Overall, while participation in flexibility services can have an impact on the lifetime of HPs, careful planning, design, and maintenance can help to mitigate these risks and ensure that the HPs provide reliable and efficient service throughout their lifetime.

- For batteries, to mitigate the impact of flexibility on system lifespan, FSP can implement battery management strategies, such as optimizing battery cycling, monitoring, and controlling battery temperature and performing regular maintenance and testing.

- For P2G systems, to mitigate the impact of flexibility on its lifetime, FSP can implement measures such as thermal management, control optimization, and preventive maintenance. By ensuring that P2G systems are operated within their optimal operating conditions and monitoring their performance, FSP can maximize their lifetime and reliability, while also providing valuable flexibility services to the grid.

- ***Challenging control of the different assets***

One another significant drawback for FSPs is the challenging control of different flexibility assets, which can be attributed to the operational complexity involved. When managing a diverse portfolio of flexibility assets FSPs have difficulties in coordinating and controlling these assets effectively.

- When managing a mix of flexibility assets such as batteries, heat pumps, and power-to-gas (P2G) systems, the control and coordination of these assets can be complex.
- Specifically, when multiple heat pumps (HPs) are utilized as flexibility assets, controlling them collectively becomes challenging due to their varying operational characteristics and response dynamics.
- Operational complexity increases when different asset types, like batteries and P2G systems, are integrated into the flexibility portfolio, each with its own unique requirements and compatibility considerations.
- Managing the control of multiple HPs or a mix of different assets requires addressing technical aspects such as communication protocols, synchronization, load balancing, and resource allocation.
- Additionally, operational factors including maintenance schedules, system monitoring, fault detection, and troubleshooting contribute to the operational complexity.

Mitigation Strategies:

- Implement centralized control strategies: Design centralized control strategies that can intelligently manage and optimize the behavior of diverse assets, improving their collective performance and response to flexibility needs.

- Develop asset-specific flexibility offer algorithms: Develop asset-specific flexibility offer algorithms that consider the unique characteristics of each asset. These algorithms enable precise control and coordination of asset behavior to meet flexibility needs. By considering factors like technical capabilities, response times, operational constraints, and limitations, flexibility service providers can effectively manage and optimize the behavior of different assets. The algorithms allow for adjustments and optimization of asset operations, ensuring their collective performance aligns with flexibility requirements. By dynamically adjusting control parameters and strategies based on the specific characteristics of each asset, the asset-specific flexibility offers algorithms to maximize the precision of flexibility offers by different flexibility assets.

- Enhance communication and interoperability: Ensure compatibility and interoperability among different asset types by implementing standardized communication protocols and data exchange formats. This simplifies asset integration and control.

- Conduct comprehensive asset monitoring: Implement robust monitoring systems to continuously assess the performance and condition of flexibility assets. This enables proactive maintenance, fault detection, and rapid troubleshooting.

- ***Time consumption***

"Time consumption" is indeed a drawback of flexibility services, as it can be time-consuming and requires significant effort to implement and maintain the flexibility services. This includes activities such as planning, scheduling, dispatching, receiving request, sending offer, monitoring, and reporting. The complex nature of handling multiple assets, responding to flexibility requests, and ensuring timely delivery of services can be resource-intensive and time-consuming.

1- Establish effective communication and control systems: This can involve implementing specialized hardware and software systems to monitor and control energy consumption and production for flexibility purposes, as well as establishing secure communication channels with third-party partners such as OIKEN. This can be a complex and time-consuming process that requires significant expertise and resources.

2- Legal and regulatory requirements: FSP must comply with some regulatory requirements to provide flexibility services. This can involve obtaining licenses, permits, and approvals from responsible organizations, as well as establishing contracts with other parties involved in the energy market. These processes can also be time-consuming and require significant effort and resources.

➢ FSPs need to invest considerable effort in optimizing their processes to minimize time consumption and improve operational efficiency. It may also need to leverage automation and other technologies to streamline the implementation and maintenance of these services, reducing the time and resources required to provide them.

- ***Operational Complexity and Revenue Uncertainty***

Operational complexity is a significant drawback faced by FSPs in the current market. It arises from various challenges related to the infrastructure, pricing mechanisms, market participant interactions, revenue uncertainty, regulatory requirements, and communication channels. Here's a breakdown of these problems:

1. Infrastructure of Flexibility Services: FSPs encounter complexities in the infrastructure of flexibility services, which include:
    - Pricing Mechanisms: Determining the remuneration price for the flexibility offered by FSPs, which involves considerations such as market conditions, demand, supply, and regulatory frameworks.
    - Market Participant Interactions: Understanding the roles and interactions between FSPs, aggregators like OIKEN, energy suppliers, grid operators, and end consumers. Effective coordination and collaboration among these stakeholders are crucial for smooth flexibility operations.
    - Uncertainty in Revenue: FSPs face revenue uncertainty due to factors like market price volatility and uncertainties in contractual agreements, which make it challenging to predict and forecast revenue accurately.
2. Regulatory Requirements: FSPs must comply with regulatory and legal obligations to provide flexibility services. This involves obtaining licenses, permits, and approvals, adhering to market rules, and establishing contracts with other market participants.
3. Communication Channels: Efficient communication channels play a vital role in facilitating seamless interactions among participants in flexibility programs. Establishing effective communication channels is essential for timely information exchange and coordination between FSPs, aggregators, and other stakeholders.

The conceptual framework for operational complexity is presented in Figure 38. The figure illustrates the interactions between various modules within the flexibility program/process. It highlights the relationships and flow of information between these modules, emphasizing the complexity involved in managing and coordinating flexibility services.

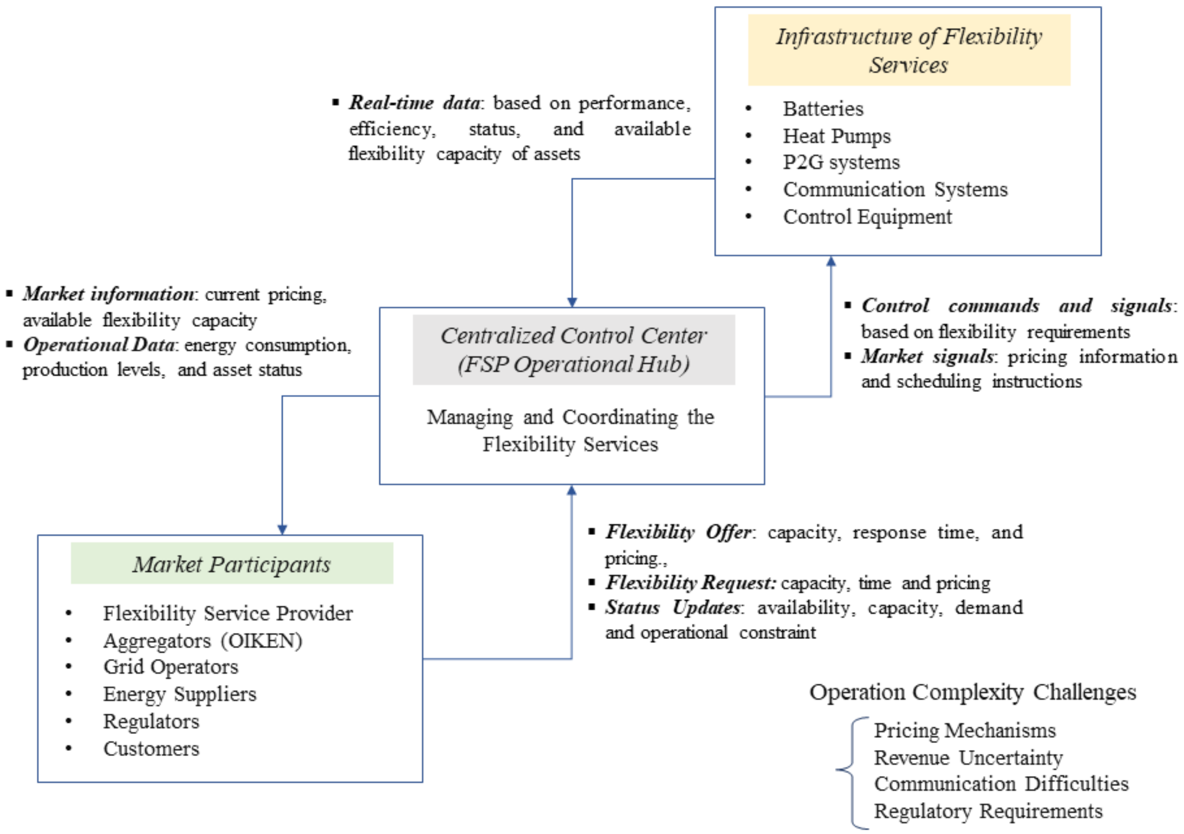

Figure 38 The conceptual framework for operational complexity of flexibility services

To address the operational complexity associated with these problems, FSPs can consider the following strategies:

- Continuous Monitoring: Regularly monitor market conditions, pricing mechanisms, and regulatory changes to adapt strategies and mitigate revenue uncertainty.
- Collaboration and Partnerships: Foster collaborations among FSPs, aggregators, and market participants to share knowledge, best practices, and innovative solutions.
- Streamlined Processes and Automation: Implement streamlined processes and leverage automation technologies to simplify operational workflows, reduce manual efforts, and enhance efficiency.
- Regulatory Compliance: Stay up-to-date with regulatory requirements and ensure compliance to avoid potential legal issues and ensure smooth provision of flexibility services.
- Effective Communication: Establish efficient communication channels to facilitate real-time information exchange and coordination among market participants.

5. Summary and conclusions

This report provides a comprehensive assessment and evaluation of flexibility test cases related to deliverable 8.3. The findings highlight the benefits and drawbacks of flexibility services and the valuable lessons learned from the test cases. The main objectives achieved in this report in both site pilots of Turkey and Swiss are:

5.1 OEDAS pilot site

During the demo activities, the test cases conducted were evaluated within the scope of the report, focusing mainly on the following aspects:

- Some KPIs have been established to measure the performance of assets (battery storage and EV chargers) in the flexibility provisioning process. These KPIs are designed to evaluate the process from both the DSO and FSP perspectives, allowing for comprehensive assessment.
- If we delve into the details, the KPIs are structured into three main groups: technical, economic, and environmental. Economic KPIs are primarily designed to indicate the revenue obtained by the FSP throughout the process in a straightforward manner.
- The basic structure of the Turkish electricity market has been presented, providing information on the level of market compatibility of the conducted studies. Descriptions have been provided regarding the current state of flexibility concept, possible services, and the flexibility potentials of the assets used in the demo activities in Turkey.
- Finally, the benefits of the flexibility process for DSO have been examined. In this section, the risks associated with the flexibility delivery process have been analysed from both FSP and DSO perspectives.

Also, the main lessons learnt during these evaluations have been:

Technical evaluation of assets:

- It has been observed that both electric vehicles and battery storage systems can provide flexibility to the grid, both individually and together, with similar performance levels, as demonstrated by the defined scenarios. Smart charging concept offers a valuable option on this point.
- Battery storage systems and electric vehicles are capable of quickly responding to setpoints determined for flexibility demand.
- The flexibility delivery rate is quite high for batteries. The same applies to electric vehicles but the charging curve of the vehicle battery tends to slow down when the state of charge is above 80%, regardless of the setpoint given.

Benefits of flexibility for congestion management:

- To manage the grid congestion problems (in Turkish demo, this means the reduction of local transformer load) activating demand side management is crucial.
- It is possible to reduce transformer consumption during peak times by using electric vehicles as flexibility assets in coordination with the end user.

- With the offering of dynamic tariff structures, it is possible for FSPs to participate in the flexibility delivery process and generate profits.
- Conducting electric vehicle charging sessions with the load support of battery storage systems provides greater benefits in preventing grid congestion issues.

Technological requirements for flexibility provisioning:

- To manage flexibility delivery process, platforms that include real-time monitoring, advanced control options and the ability to track asset availability are necessary.
- Although managing different assets (EVs, batteries, PV, etc.) with a single platform may involve more complex requirements, it is more practical and advantageous for congestion management.
- In a realistic scenario, strong communication networks between DSOs, FSPs, and other partners, if applicable, are essential for the effective management of the flexibility delivery process.

5.2 Swiss pilot site

- **Development of an evaluation method and definition of flexibility KPIs:** The report introduces a method for assessing the economic and reliability aspects of flexibility test cases. It defines and explains the appropriate KPIs to measure and evaluate flexibility test cases.
- **Assessment of test cases from reliability and economic perspectives:** All flexibility test cases are thoroughly evaluated using the defined KPIs. The assessment encompasses both qualitative and quantitative analysis. The economic analysis examines flexibility costs, such as levelized cost of energy and operational costs, as well as remuneration, penalties, and revenue analysis. The reliability analysis considers Flexibility Deviation Ratio (FDR), Predicted Flexibility Reliability (PFR), and Flexibility Availability Index (FAI).
- **Investigation and suggestion of remuneration for economic justification of flexibility services:** The report calculates the critical remuneration price, which indicates the point where the revenue for the flexible service provider is zero. It provides insights into economic justifications for providing flexibility, considering remuneration above this threshold.
- **Assessment of market structure and compatibility for adopting flexibility services:** The report investigates the current situation of flexibility services in the electricity market of both pilot sites, from market situation, regulations, and legislation. It assesses the market compatibility and flexibility potential for different test cases.
- **Comprehensive evaluation of benefits and drawbacks of flexibility provisions from FSP and DSO perspectives:** By analysing the results of test case evaluations, the report presents a general assessment of the benefits and risks associated with each test case and specific flexibility assets. Key risks identified include potential overconsumption, availability, installation lifetime, control challenges, time consumption, operational complexity, and revenue uncertainty.
- **Provision of mitigation strategies to address the identified risks associated with flexibility test cases:** For each identified risk associated with flexibility services, the report suggests mitigation strategies to facilitate the future development of flexibility services.

Also, the main lessons learnt during these evaluations are:

Economic and reliability justification for flexibility:

- Price differences may not justify flexibility economically.
- Critical remuneration prices are essential for assessing asset viability.
- Heat Pump assets are economically viable compared to batteries.
- Batteries offer high reliability for flexibility services.
- SOFC and SOEC assets have acceptable reliability but limited economic justification.
- Negative requests perform better economically and reliability-wise than positive requests.

Synergy and disadvantage of combined assets:

- Integrating batteries with other assets enhances reliability and economics.
- Batteries improve the performance of other assets by compensating for inefficiencies.
- Multiple Heat Pump assets generate more revenue but have lower reliability.
- Integrating assets offers economic advantages but presents control challenges.

Mitigation strategies for risks:

- Implement demand-side management techniques and develop robust flexibility offer forecasting models.
- Deploy advanced control systems for optimized asset performance and implement preventive maintenance practices.
- Diversify resource portfolios to mitigate availability risks and develop resilient control systems for real-time monitoring and troubleshooting.
- Foster collaborations with partners, among FSPs, aggregators, and market participants, for expertise and availability and Streamline processes for better operational efficiency.
- Optimize control strategies to prolong asset lifetime and Leverage automation and technology for implementation and maintenance.
- Establish efficient communication channels for real-time information exchange.

5.3 General Conclusion

In this report, the assessment and evaluation of flexibility test cases in the Turkish and Swiss pilot sites have provided insights into the benefits, drawbacks, and lessons learned. Electric vehicles and battery storage systems were found to effectively contribute to grid flexibility, improving reliability and economic viability. Dynamic tariff structures, demand-side management, and real-time monitoring were identified as important factors for efficient flexibility delivery. The other analysis revealed important findings about the economic and reliability perspectives of flexibility. It is necessary to determine critical remuneration prices to assess the economic viability of each flexibility asset. Battery assets were found to be reliable and suitable for flexibility services, while heat pump (HP) assets showed better economic viability compared to batteries and power-to-gas (P2G) systems. However, HP assets exhibited lower reliability than batteries and other assets. SOFC and SOEC assets demonstrated acceptable reliability but had limited economic justification. Negative request cases showed better economic and reliability performance compared to positive request cases.

The evaluation also emphasized the need for regulatory support and collaboration among stakeholders to enable proposed business models. Mitigation strategies, such as optimizing control strategies and implementing preventive maintenance practices, were proposed to address risks associated with flexibility services.

This report offers specific separated insights from the Turkish and Swiss demonstrations and valuable recommendations for implementing and managing flexibility in the energy sector. By adopting suggested mitigation strategies and considering identified risks and opportunities, stakeholders can enhance grid optimization, market dynamics, and operational efficiency. Overall, this report provides guidance for successful flexibility implementation, contributing to the progress of the FlexiGrid project and supporting a sustainable energy future.

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