STREAMING FLEXIBILITY
TO THE POWER SYSTEM

D6.1 TECHNICAL, ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENT

Delivery Date: September 2026

STREAM

STREAMING FLEXIBILITY TO THE POWER SYSTEM

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Responsible	Organisation	Contributing WP
Benjamin Grellier	JR	WP6

Authors (organisation)

Benjamin Grellier (JR), Ismo Heimonen (VTT), Ashish Saini (VTT), Lisa Leitner (JR), Johanna Pucker-Singer (JR), Martin Beermann (JR), Ladislaus Lang-Hogrefe (JR), Jan Jeriha (IRI UL), Janez Gregor Golja (UL), Tomi Medved (UL), Darja Skrt Georgiev (CYG), Denis Sodin (COMS), Diego Garcia (ETRA), Daniel Pastor Pascual (ETRA), Bernardo Di Chiara (OPT)

Abstract

Deliverable D6.1 presents the STREAM framework and results for technical, environmental and social impact assessment across the Slovenian, Spanish, Italian and Finnish pilots. The assessment identifies technically viable flexibility pathways across all pilots, pilot-specific environmental benefits where flexibility avoids reinforcement or shifts consumption towards photovoltaics, and generally positive but conditional social acceptance.

Keywords

Impact assessment; technical impact; environmental impact; social impact; local flexibility markets; distributed energy resources; key performance indicators; mitigation; STREAM

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EXECUTIVE SUMMARY

STREAM partners developed and demonstrated an integrated set of tools to support flexibility services for DSOs, aggregators, market operators, energy communities, flexibility providers and end users. The set of STREAM tools includes:

- sDATA for data collection and exchange,
- sGRID and sPLAN for grid monitoring, forecasting and planning,
- sFLEX and the Device Registry for flexibility management, registration and prequalification,
- sMART for local flexibility markets,
- sENC for energy-community aggregation and optimisation.

The STREAM impact assessment provides an overall picture of the demonstrations performed in the project. It covers three main categories: Technical, Environmental and Social impacts, assessed across the four pilot sites in Slovenia, Spain, Italy and Finland.

This report can be read in parallel with D5.1 – Demonstration Activities Report, which describes the test cases and demonstrations. D6.1 uses these results to assess their technical, environmental and social impacts. D6.2 complements the assessment with the economic perspective.

The assessment is built on the final KPIs set defined in D5.1. D2.1 and D2.3 provide additional information on the user, service and business context. **Technical** results are based on measurements, calculations and controlled or simulated cases. **Environmental** impacts are assessed through life-cycle assessment (LCA), using Global Warming Potential and Cumulative Energy Demand as impact indicators. The **social** assessment uses surveys and questionnaires adapted to the different pilot participants.

D6.1 assesses 32 final technical KPIs. The environmental assessment uses GWP and CED indicators, while the social assessment combines formal KPIs with pilot-specific indicators.

Table 1: Assessment areas and main indicators

Assessment area	Main KPIs / indicators
Technical – Slovenia	Data and communication reliability; grid investment savings; load, generation and grid-state forecasting; bid success; device registration and prequalification
Technical – Spain	Congestion forecasting and resolution; automatic bidding; local self-consumption; voltage deviations; prequalified assets; flexibility availability, coverage and compliance; economic welfare
Technical – Italy	Response to flexibility request; HVAC flexibility; renewable self-consumption; transformer forecast; registered providers; grid reconstruction
Technical – Finland	FCR activation speed; flexibility estimation accuracy; bid acceptance
Environmental	GWP; total, renewable and non-renewable Cumulative Energy Demand
Social	Customer participation and satisfaction; motivation; integration; comfort; trust; control; operational risks; roles and responsibilities

The main conclusions observed for the pilots are the following:

- **Slovenia**: The Ajdovščina pilot demonstrated the flexibility chain from data exchange and forecasting to grid planning, registration, market participation and TSO services. The planning assessment considered PV, PV+BESS, EV+HP, EV+HP+PV and combined configurations under different grid-stress levels to assess the value of flexibility in comparison to grid reinforcement. Grid investment savings reached 86.6–100% under reference conditions and 39.8–100% under high-stress conditions, depending on the technology configurations. Flexibility also reduced the environmental impacts linked to grid reinforcement, although electricity production remained the main source of impact. The four industrial respondents were generally positive regarding the use of flexibility, but production continuity, cybersecurity, transparency and the possibility to override flexibility activation remained important.
- **Spain**: The Crevillent pilot combined an energy community, PV, battery storage, EV charging and prosumer flexibility. It achieved a 93.6% local self-consumption ratio when using flexibility, while the community battery was associated with a 30.8% reduction in voltage deviations. Twenty assets were prequalified, but average flexibility availability was 28.3%, flexibility request coverage 27%, and provision compliance 67.2%. In the environmental assessment, the grid reinforcement alternative produced the lowest GWP at 139 g CO_2e/kWh, compared with 146 g CO_2e/kWh for the battery case. The 40 survey participants showed strong social and environmental motivation and generally positive trust in flexibility services, while clear information and user control remained important.
- **Italy**: The Terni pilot assessed flexibility from EV charging, residential HVAC loads and water pumping. Around 71% of the 41 residential meters retained after data-quality screening showed detectable temperature-dependent consumption. For the water pumping system, PV-aware pump scheduling increased local PV use by 35.2% and reduced GWP by 29% and non-renewable CED by about 30% compared with the baseline schedule. These results represent optimisation over a representative 24-hour period, with pilot PV production increased fivefold for the calculation. Household and EV-user responses were positive for joining flexibility schemes, although the sample was small. Water-sector participants stressed that continuity of supply, emergency operation and retained operator control must be protected.
- **Finland**: The Finnish pilot used aggregated residential heating loads for FCR-D up and down services. Tests showed that small heating loads can be aggregated and controlled according to grid-frequency signals, although flexibility estimation and control performance still require improvement for larger portfolios. The demonstration used a small portfolio, and bid acceptance was simulated rather than tested through a live Fingrid market interface. FCR-D operation changed annual heating electricity consumption by less than 1%. The main additional environmental burden came from control hardware, estimated at 0.6–1.3 t CO_2e in the upscaled case, compared with about 100 t CO_2e for the assessed battery reference. The three household respondents reported high scores in comfort and integration, while trust was lower, particularly regarding data protection, system reliability and external control.

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1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

The purpose of this deliverable is to present the results of the technical, environmental and social assessment for the STREAM project. The assessment is presented for each pilot site and, where applicable, for upscaled future scenarios.

The work was carried out under T6.1, where the planning for the monitoring and evaluation across all pilot sites was defined. Under T6.3, the actual technical, social and environmental impact assessment was conducted.

It builds on Deliverable D2.2, which defined the initial use cases and KPIs, and on Deliverable D5.1, which updated the final set of KPIs. D2.1 [1] and D2.3 [2] provide the user, service and value context needed to interpret those impacts.

The technical KPIs were directly calculated by the pilot partners, while the environmental impact assessment was done by JR, based on data provided by the pilot sites. Regarding the social impact assessment, JR (with the partner's collaboration) established personalised questionnaire to assess the acceptability of the flexibility services demonstrated by STREAM.

1.2 SCOPE OF THE DOCUMENT

D6.1 presents the technical, environmental and social impacts of the solutions and services implemented within STREAM. For the technical impact assessment, the previously defined KPIs were assessed and interpreted. Economic impacts are reported separately in D6.2, while scalability and replication are addressed in D6.3.

1.3 STRUCTURE OF THE DOCUMENT

Sections 2, 3 and 4 present the technical, environmental and social impacts. Section 5 provides the conclusions. Section 6 contains the references and acronyms. Annex A provides additional environmental assessment information and results.

2 TECHNICAL IMPACT ASSESSMENT

2.1 LIST OF TECHNICAL KPIS AND METHODOLOGY

The technical impact assessment evaluates the performance of the STREAM solutions and services across the Slovenian, Spanish, Italian and Finnish pilot sites. It builds on the final pilot KPI set and the final demonstration definitions reported in D5.1. The KPIs focused on how distributed flexibility can be integrated in practice, covering reliable data and communication, grid visibility and forecasting, flexibility activation, congestion and voltage management, and the technical processes for market participation, asset registration and prequalification.

Because the four pilots tested different assets and flexibility services, the evaluation basis differs between results. The relevant period, unit, scenario and test conditions are therefore reported with each pilot result. Results are either derived from operational measurements or modelled scenarios.

Pilot-level conclusions are based on the technical effects supported by results of the KPIs. Cross-pilot synthesis focuses on common technical impact and enabling conditions, since the pilots address different services, assets, network conditions and demonstration boundaries.

Table 2 presents the final list of the assessed KPIs for each pilot and the related tools.

Table 2: Final technical KPI set and demonstration-definition status

Pilot	KPI ID	Final KPI name	Unit	Primary tool(s)
Slovenia	SI.01	Data collection reliability	%	sFLEX, sGRID, sMART / sDATA
Slovenia	SI.02	STREAM tools communication reliability	%	sFLEX, sGRID, sMART, sDATA
Slovenia	SI.03	Grid investment savings ratio (GISR) due to the flexibility utilization	%	sPLAN
Slovenia	SI.04	Load and generation forecast accuracy	% (WMAPE) kW (MAE and RMSE)	sGRID
Slovenia	SI.05	Grid state forecast accuracy	% (WMAPE) kW (MAE and RMSE)	sGRID
Slovenia	SI.06	Bid success rate	%	sFLEX, sMART
Slovenia	SI.07	Number of Devices Registered	number	sFLEX / Device Registry
Slovenia	SI.08	Total Nominal Capacity of Registered Devices	MW	sFLEX / Device Registry
Slovenia	SI.09	Percentage of Devices with failed Communication	%	sFLEX / Device Registry
Slovenia	SI.10	Percentage of Prequalified Devices	%	sFLEX / Device Registry

Slovenia	SI.11	Number of Devices Prequalified	number	sFLEX / Device Registry
Slovenia	SI.12	Total Capacity of Prequalified Devices	MW	sFLEX / Device Registry
Spain	ES.02	Congestion forecast accuracy	%	sGRID
Spain	ES.03	Congestion correctly identified	%	sGRID
Spain	ES.04	Congestion resolution ratio	%	sGRID, sMART, sFLEX, sENC
Spain	ES.05	Correct automatic bids ratio	%	sENC, sFLEX, sMART
Spain	ES.06	Local self-consumption ratio	% and MWh	sMART, sFLEX, sENC
Spain	ES.07	Reduction of voltage deviations	%	sGRID
Spain	ES.08	Number of prequalified assets	number	sGRID, sFLEX, sENC, sMART
Spain	ES.09	Flexibility provision compliance ratio	%	sFLEX, sENC, sMART, sGRID
Spain	ES.11	Flexibility requests coverage	%	sGRID, sFLEX, sENC, sMART
Spain	ES.13	Increase of economic welfare	€	sFLEX, sENC, sMART
Spain	ES.14	Percentage of flexibility availability	%	sFLEX, sENC, sMART
Italy	IT.02	Response to flexibility request	%	sMART
Italy	IT.03	Share of users with detectable HVAC flexibility	%	sFLEX
Italy	IT.04	Increase in local renewable energy self-consumption	%	sENC
Italy	IT.05	Accuracy of transformer loading forecast	%	sGRID
Italy	IT.06	Number of registered flexibility providers	number	sMART
Italy	IT.07	Accuracy of grid reconstruction	%	sGRID
Finland	FI.01	FCR activation speed	service-specific compliance triplet	sFLEX, sDATA
Finland	FI.02	Flexibility estimation accuracy	%	sFLEX, sDATA

Finland	FI.05	Bid acceptance rate	%	sFLEX, sDATA

2.2 SLOVENIAN TECHNICAL IMPACT

The Slovenian pilot is located in the Ajdovščina industrial zone, where growing industrial demand creates both operational and network-planning challenges for Elektro Primorska. Flexibility is drawn from heterogeneous assets, including industrial cooling and process loads, photovoltaic generation and EV charging stations, and is coordinated through the STREAM ecosystem. The pilot demonstrates flexibility provision to the local flexibility market for Distribution System Operator (DSO) congestion management, participation in TSO manual Frequency Restoration Reserve (mFRR), and the use of flexibility as an option alongside conventional grid reinforcement in network planning.

The Slovenian technical evaluation covers data exchange, tool communication, grid planning and forecasting, market bidding, device registration and prequalification. The summary table separates available demonstration results from KPI rows for which the result remains outside the current readiness authorisation [3].

Table 3: Slovenian technical KPI result status

KPI ID	KPI name	Result	Unit	Assessment period / comparator
SI.01	Data collection reliability	97.9% (smart meters) 100% (control) 99.99% (SCADA) 100% (Flexibility assets - Siemens) 99.7% (Flexibility assets - Reduxi)	%	all eligible expected data records or transfers in the assessed interface and period
SI.02	STREAM tools communication reliability	99.0% (sDATA platform) 100% (sGRID–sMART, sFLEX–sMART, sDATA–DR).	%	all eligible communication attempts for each assessed tool pair
SI.03	Grid investment savings ratio (GISR) due to the flexibility utilization	86.6–100% (reference) 39.8–100% (high-stress) across scenarios	%	the matched reinforcement or grid-upgrade case without flexibility
SI.04	Load and generation forecast accuracy	Median relative MAE 7–12% across all load categories (DA and ST). Median WMAPE 15–67% depending on category and horizon	% (WMAPE) kW (auxiliary errors)	actual metered power over the same matched forecast windows
SI.05	Grid state forecast accuracy	MV feeders and HV/MV substation: WMAPE 13–19% (ST). MV/LV transformer stations: WMAPE 41–47% (DA); MAE ~10–15% of peak loading across all elements.	%	matched observed/reference grid-state values for the same grid elements and forecast windows
SI.06	Bid success rate	100% of bids accepted 93.6% by volume.	%	all eligible submitted bids in the defined market sessions
SI.07	Number of Devices Registered	13 devices registered across five demonstration locations.	number	Demonstration registration period

SI.08	Total Nominal Capacity of Registered Devices	0.538 MW aggregate nominal capacity registered across 13 devices: three PV locations totalling 0.450 MW and four EV charge points totalling 0.088 MW.	MW	registered-device population at the defined reporting point
SI.09	Percentage of Devices with failed Communication	0 of 13 registered devices failed the communication check (0%) during the controlled prequalification tests.	%	all registered devices eligible for the communication check
SI.10	Percentage of Prequalified Devices	100% of the 13 registered devices passed the reported prequalification test.	%	Prequalification demonstration
SI.11	Number of Devices Prequalified	13 devices were prequalified.	number	Prequalification demonstration
SI.12	Total Capacity of Prequalified Devices	All 13 registered devices were prequalified; their aggregate nominal capacity was 0.538 MW. D5.1 does not report a single consolidated flexible-capacity total.	MW	the set of devices that successfully passed prequalification

2.2.1 SI.01 - Data collection reliability

Table 4: SI.01 - Data collection reliability — KPI definition and assessment

Item	Information
Definition	Percentage of expected data transmissions or records successfully received for each assessed data source
Unit	%
Scope	smart meters, transformer-station control measurements, SCADA measurements and flexibility-asset measurements; related UCs SI.02, SI.04, SI.05, SI.06 and SI.08
STREAM tool(s)	sFLEX, sGRID, sMART
Calculation inputs	Number of successful transmissions or records, total expected transmissions, data source/device, observation period and exclusions
Comparison / assessment rule	All expected transmissions for each assessed data source during the defined period; results are reported separately by data source

$$Data_{Reliability} = \frac{N_{successful}}{N_{total}} \times 100$$

Equation 1: SI.01 calculation

The Slovenian pilot relies on two independent data collection infrastructures: the DSO's (EPR) metering and SCADA systems, which provide smart meter, transformer control, and SCADA measurements, as well as the sFLEX platform, which collects measurements from flexibility assets via dedicated communication interfaces. Table 5 presents the aggregate results per data source.

Table 5: Data collection reliability by source

Sub-KPI	Data source	Devices/channels	Aggregate	Min	Max
SI.01a	Smart meters (EPR AMI)	2356	97.9%	0.0%	100%
SI.01b	Transformer control (EPR AMI)	19	100%	100%	100%
SI.01c	SCADA (EPR)	10	99.99%	99.95%	100%
SI.01d	Flexibility assets — Siemens (sFLEX)	3	100%	100%	100%
SI.01e	Flexibility assets — Reduxi (sFLEX)	16	99.7%	99.6%	100%

For smart meters (SI.01a), the vast majority (96%) achieved reliability above 91%, as shown in Figure 1. A small number of meters (9) showed reliability below 50%, likely due to device or communication faults at individual metering points.

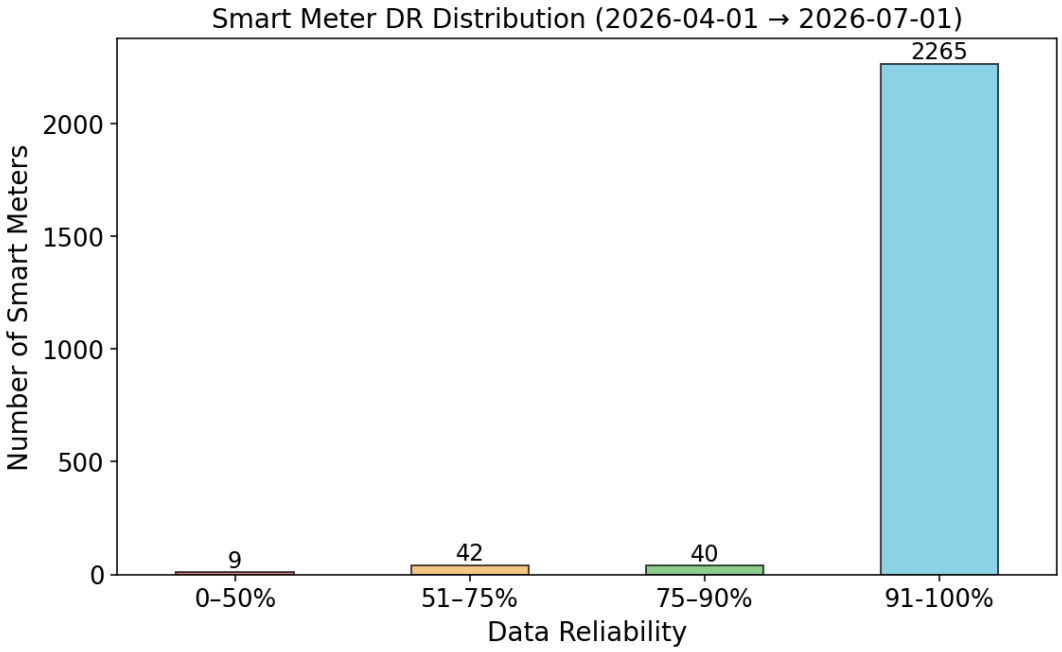


Figure 1: Smart meter data reliability distribution

Transformer control measurements (SI.01b) are available for 19 of the 36 transformer stations in the network. The remaining 17 are not equipped with control measurement devices. All 19 equipped stations achieved 100% data delivery.

SCADA measurements (SI.01c) cover active and reactive power for four MV feeders and the HV/MV primary substation (10 channels total). Reliability is 99.95% or above for all channels, with only 4 timestamps missing on a single channel over the entire three-month period.

Flexibility asset measurements (SI.01d) are collected via sFLEX through two communication paths. Three industrial assets (Incom, Mlinotest) are connected via Siemens controllers with redundant connectivity (Ethernet and mobile data), achieving 100% reliability. The remaining 16 devices (PV installations, BESS, and hybrid inverters at Metal Design, Petrič, and Tosla) are connected via Reduxi HEMS gateways, with aggregate reliability of 99.7% and per-device reliability ranging from 95.6% to 100%.

The high reliability across all data sources confirms that the measurement infrastructure provides a dependable foundation for the sGRID forecasting and grid state estimation workflows, as well as for the sFLEX flexibility monitoring and bid preparation processes.

2.2.2 SI.02 - STREAM tools communication reliability

Table 6: SI.02 - STREAM tools communication reliability — KPI definition and assessment

Item	Information
Definition	Percentage of expected exchanges between the relevant STREAM tools that are completed successfully
Unit	% per assessed connection
Scope	tool-to-tool integration and demonstration runs; related UCs SI.02, SI.05, SI.06 and SI.08
STREAM tool(s)	sFLEX, sGRID, sMART, sDATA
Calculation inputs	Successful exchanges, total expected exchanges, tool pair, test or session identifier and assessment period
Comparison / assessment rule	All expected exchanges for each assessed tool-to-tool connection during the demonstration runs

$$CommunicationReliability = NsuccessfulNtotal \times 100$$

Equation 2: SI.02 calculation

Table 7 presents the communication reliability per connection.

Table 7: KPI SI.02, communication reliability per connection

Connection	Reliability	Test population	Connected test cases
sDATA ↔ sGRID/sFLEX	99.0%	API requests during operational test period (Spring 2026)	sDATA-UC.01.01 SI-UC.02.01
sDATA ↔ Device registry	100%	Device registrations synchronized to sMART	SI-UC.02.01 SI-UC.07.01
sGRID → sMART	100%	Congestion messages across demonstration sessions	SI-UC.02.01
sFLEX → sMART	100%	Flexibility bids across demonstration sessions	SI-UC.02.01 SI-UC.06.02

The sDATA platform achieved 99.0% API response success rate during the operational test period, covering data provisioning to both sGRID (grid measurement) and sFLEX (EV charging station data). The remaining 1% of failed requests were handled through the platform's error logging and retry mechanisms without data loss.

The sDATA–Device Registry connection was validated through the registration and synchronization of all 13 flexibility devices to sMART, confirming that asset metadata (metering point IDs, prequalification status, aggregator assignment) was correctly available for bid eligibility validation.

The sGRID–sMART and sFLEX–sMART connections were validated during the demonstration sessions documented in SI-UC.02.01. All congestion messages transmitted by sGRID were correctly received by sMART and resulted in auctions with the correct parameters (location, flexibility volume, direction, ISP). All flexibility bids submitted by sFLEX were correctly received and placed in the auction order book, subject to the eligibility checks performed by sMART against the Device Registry.

2.2.3 SI.03 - Grid investment savings ratio (GISR) due to the flexibility utilization

Table 8: SI.03 - Grid investment savings ratio (GISR) due to the flexibility utilization — KPI definition and assessment

Item	Information
Definition	Relative reduction in grid-reinforcement cost when flexibility is used instead of the matched reinforcement case
Unit	%
Scope	grid-planning assessment using future technology and grid-stress scenarios; related UC SI.01
STREAM tool(s)	sPLAN
Calculation inputs	Reinforcement cost without flexibility, cost in the flexibility-enabled case, network scenario, stress level and planning horizon
Comparison / assessment rule	Matched grid-reinforcement case without flexibility

$$GISR = \frac{C_{reinf} - C_{flex}}{C_{reinf}} \times 100$$

Equation 3: SI.03 calculation

The GISR was evaluated using the sPLAN grid planning tool across 15 future scenarios covering five technology combinations (PV, PV + BESS, electrification, electrification+ PV, combined) under three stress levels (low, reference, high), with the current network state as the baseline (test case SI-UC.01.01). Network reinforcement candidates were identified using a 90% planning loading threshold for both lines and transformers.

Flexibility was valued at an activation price of 100 €/MWh, while PV curtailment was assumed at 0 €/MWh. A detailed discussion of the cost assumptions and their sensitivity is provided in D6.2.

Table 9 presents the GISR for each scenario and stress level.

Table 9: SI.03 - GISR

Scenario	Low-stress	Reference	High-stress
PV	0 %	100 %	100 %
PV + BESS	0 %	100 %	100 %
Electrification	97.67 %	89.16 %	43.23 %
Electrification + PV	0 %	86.64 %	39.84 %
Combined	0 %	97.40 %	64.31 %

A GISR of 0% indicates that no reinforcement was required under the baseline conditions for that scenario, so flexibility cannot provide any savings.

In the PV and PV+BESS scenarios, all identified reinforcement costs under reference and high-stress conditions can be fully avoided through PV curtailment (GISR 100%), as the congestion is exclusively caused by reverse power flow during generation peaks and can be resolved without physical network upgrades.

In the electrification scenarios, flexibility covers nearly all reinforcement needs under low stress (GISR 97.7%), where the number of additional EVs and heat pumps is still relatively modest. As the level of electrification increases, however, a progressively larger share of the required reinforcement cannot be replaced by flexibility, with GISR declining to 89.2% under reference and 43.2% under high-stress conditions.

The combined scenario, which includes all technology types together, retains substantial savings: 97.4% under reference conditions and 64.3% under high stress. The inclusion of PV and BESS alongside electrification partially offsets the demand growth, allowing flexibility to remain effective over a wider operating range than in the pure electrification case.

2.2.4 SI.04 - Load and generation forecast accuracy

Table 10: SI.04 - Load and generation forecast accuracy — KPI definition and assessment

Item	Information
Definition	Error between actual metered active power and the corresponding load or generation forecast
Unit	% for WMAPE; kW for MAE and RMSE; relative MAE reported as %
Scope	asset-level and aggregated forecasts for day-ahead and short-term horizons; related UCs SI.05 and SI.06
STREAM tool(s)	sGRID
Calculation inputs	Actual power, forecast power, matched timestamps, forecast horizon, asset or aggregation level and data-quality exclusions
Comparison / assessment rule	Actual metered power for the same matched forecast windows

$$WMAPE = \left(\frac{\sum_{t \in T} \left| P_{t,Actual} - P_{t,Forecast} \right|}{\sum_{t \in T} \left| P_{t,Actual} \right|} \right) \times 100$$

Equation 4: SI.04 WMAPE calculation

$$MAE = \sum_{i=t} \left| P_{t,Actual} - P_{t,Forecast} \right|$$

Equation 5: SI.04 MAE calculation

$$RMSE = \sqrt{\sum_{i=1} \left(P_{t,Actual} - P_{t,Forecast} \right)^2}$$

Equation 6: SI.04 RMSE calculation

The sGRID tool produces load forecasts for all monitored points in the SI pilot site. Two forecast horizons are evaluated: day-ahead for the following day, and short-term, which ran every 15 minutes for a one-hour horizon. Both operated fully automatically during the evaluation period (23 April – 21 May 2026, test case SI-UC.05.01). Results from earlier operational runs (starting 13 April) were excluded due to calibration of the grid model.

Forecasts are produced for 141 individual load points including individual consumer loads of varying size (small: <30 kW, medium: 30–300 kW, large: ≥300 kW connected power), transformer-level control measurements, and aggregated profiles at the transformer station level. Accuracy is evaluated against 15-minute measurements from EPR AMI system.

To enable meaningful comparison across load categories of different sizes, we introduce an additional metric: relative MAE, defined as the MAE normalised by the peak observed absolute power of each load:

$$Relative\ MAE = \frac{MAE}{max_{t \in T} \left| P_{t,actual} \right|} \times 100$$

Equation 7: SI.04 Relative MAE equation

This metric captures the average forecast error as a percentage of the load's observed operating range and is robust to both low-consumption and bidirectional profiles.

Table 11 presents the forecast accuracy per load category for both forecast horizons. Values are medians across all loads in each category.

Table 11: Load forecast accuracy by category (median values)

Category	n	Horizon	WMAPE (%)	MAE (kW)	RMSE (kW)	Relative MAE (%)
Individual – small (<30 kW)	78	DA	67.3	0.3	0.5	7.6
		ST	61.1	0.3	0.5	7.0
Individual – medium (30–300 kW)	29	DA	41.4	3.8	7.1	8.0
		ST	37.9	3.9	7.2	7.2
Individual – large (≥300 kW)	9	DA	33.5	39.1	53.6	11.6
		ST	27.9	30.3	43.3	7.0
Control (transformer measurements)	16	DA	25.8	14.2	18.4	9.1
		ST	19.0	11.7	15.6	8.0
Aggregated profiles	9	DA	33.3	16.5	25.6	10.7
		ST	33.3	18.2	23.4	10.6

WMAPE values for small individual loads appear disproportionately high (67% DA, 61% ST) despite the absolute error being negligible (median MAE of 0.3 kW). This is an inherent limitation of the WMAPE metric: for loads with low absolute consumption, even small absolute errors produce large percentage values because the denominator (sum of absolute actuals) is small. The same effect applies to prosumer profiles with bidirectional power flow, where the net consumption oscillates around zero.

Figure 2 shows the distribution of relative MAE across all load categories for both forecast horizons.

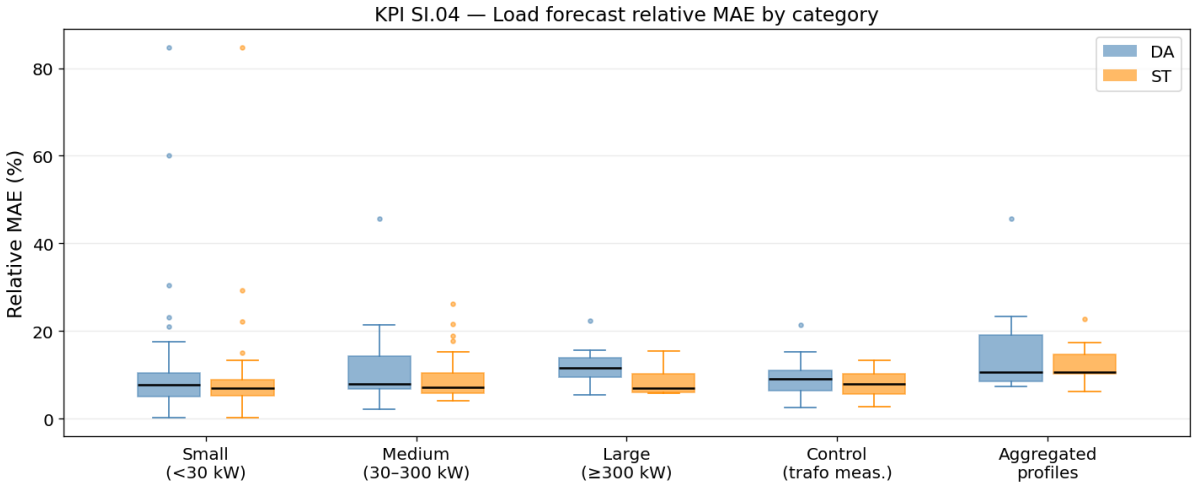


Figure 2: Box plot of relative MAE by load category

The relative MAE is consistent across all categories, with medians in the 7–11% range, confirming that forecast quality does not degrade systematically with load size. The short-term forecast improves over day-ahead most clearly for large individual loads (median relative MAE from 11.6% to 7.0%) and control measurements (9.1% to 8.0%), where predictable intraday patterns allow the ST update to correct the DA forecast. For small loads and aggregated profiles, the improvement is marginal, as these

are dominated by stochastic consumption behaviour that a one-hour-ahead update cannot fully resolve. A small number of outliers with relative MAE above 20% correspond to prosumers or highly irregular consumption profiles.

The evaluation period covers 28 days of continuous operational data, which provides a reliable assessment of typical forecast performance but does not capture seasonal variability. Shorter evaluation windows and small loads with irregular patterns contribute to wider spreads in the per-load accuracy distributions.

2.2.5 SI.05 - Grid state forecast accuracy

Table 12: SI.05 - Grid state forecast accuracy — KPI definition and assessment

Item	Information
Definition	Error between forecast grid-element loading and the corresponding measured or reference loading
Unit	% for WMAPE; kW for MAE and RMSE
Scope	MV feeders, HV/MV substation and MV/LV transformer stations; related UCs SI.05 and SI.06
STREAM tool(s)	sGRID
Calculation inputs	Forecast loading, actual/reference loading, grid-element identifier, timestamps, forecast horizon, topology/model version and exclusions
Comparison / assessment rule	Matched measured/reference loading for the same grid element and forecast window

$$WMAPE = \left(\frac{\sum_{t \in T} \left| L_{t,Actual} - L_{t,Forecast} \right|}{\sum_{t \in T} \left| L_{t,Actual} \right|} \right) \times 100$$

Equation 8: SI.05 WMAPE calculation

$$MAE = \sum_{i=t} \left| L_{t,Actual} - L_{t,Forecast} \right|$$

Equation 9: SI.05 MAE calculation

$$RMSE = \sqrt{\sum_{i=1} \left(P_{t,Actual} - P_{t,Forecast} \right)^2}$$

Equation 10: SI.05 RMSE calculation

The sGRID grid state forecast pipeline combines individual load forecasts with a power flow simulation to produce forecasted active power loading for each monitored grid element. This forecasted loading is compared against SCADA and control measurements for the same elements over the evaluation period (23 April – 21 May 2026, test case SI-UC.05.01), for both the DA and ST forecast horizons.

Eight grid elements are evaluated: four MV feeders measured via SCADA, the HV/MV primary substation (RTP Ajdovščina), and three MV/LV transformer stations equipped with control measurements. Table 13 presents the results per element.

Table 13: Grid state forecast accuracy by element type

Type	Element	Unit	Horizon	WMAPE (%)	MAE	RMSE
MV feeder	KB FRUCTAL	MW	DA	18.2	0.27	0.34
			ST	19.0	0.29	0.36
	KB MIRCE	MW	DA	18.3	0.46	0.63
			ST	13.9	0.35	0.49
	KB TALE	MW	DA	33.4	0.26	0.36
			ST	29.4	0.23	0.32
	KB ČISTILNA N.	MW	DA	15.5	0.30	0.41
			ST	13.0	0.25	0.37
HV/MV transformer	RTP AJDOVŠČINA	MW	DA	15.2	0.97	1.46
			ST	12.8	0.81	1.29
MV/LV transformer	TN0590 OC AJDOVŠČINA	kW	DA	40.0	15.9	22.6
			ST	47.2	19.0	26.2
	TN0761 OC AJD. 2	kW	DA	41.2	48.3	62.8
			ST	41.4	48.7	69.3
	TN0838 OC 3 AJDOVŠČ	kW	DA	46.3	52.2	62.6
			ST	43.5	49.2	58.4

For MV feeders and the primary substation, WMAPE ranges from 13–19% (best for ST), with MAE below 0.5 MW for individual feeders and below 1 MW for the primary substation. KB TALE and the three MV/LV transformer stations show elevated WMAPE (29–47%) due to significant distributed PV generation on these elements, which causes bidirectional power flow and a near-zero mean active power that inflates the percentage metric. When assessed in absolute terms relative to the operating range of each element, forecast accuracy is broadly comparable across all levels — MAE represents approximately 10–15% of peak observed loading for both MV feeders and MV/LV transformer stations. Residual topology mismatches at the LV level and the smaller number of loads per substation (reducing aggregation smoothing) contribute to somewhat wider error spreads at the MV/LV level, though the forecast captures the general loading profile reliably.

The ST forecast provides a clear improvement at the MV feeder and primary substation level (e.g. KB MIRCE from 18.3% to 13.9%, RTP Ajdovščina from 15.2% to 12.8%). At the MV/LV level the improvement is small.

The primary operational purpose of the sGRID grid state forecast is to support congestion detection and to inform flexibility activation through sMART. At the MV feeder and primary substation level, the forecast tracks measured loading with a WMAPE of 13–19% and MAE below 0.5 MW for individual feeders and below 1 MW for the primary substation. This level of accuracy is sufficient to distinguish

normal operating conditions from periods approaching thermal or operational limits, and the ST improvement at this level means that forecasts become more reliable precisely when operational decisions need to be finalised. At the MV/LV transformer level, accuracy in absolute terms is comparable, though residual topology uncertainties mean that localising congestion to a specific substation carries somewhat higher uncertainty than at the feeder level. During the evaluation period, grid loading remained within normal operating ranges and no congestion events were observed, so the forecast's performance specifically under near-limit conditions has not been directly validated.

The evaluation window of 28 days limits the assessment of seasonal effects, particularly the impact of varying PV generation on feeders with significant distributed generation.

2.2.6 SI.06 - Bid success rate

Table 14: SI.06 - Bid success rate — KPI definition and assessment

Item	Information
Definition	Percentage of submitted flexibility bids accepted through the demonstrated local-market clearing process
Unit	%
Scope	local flexibility-market demonstration sessions; related UCs SI.02 and SI.06
STREAM tool(s)	sFLEX, sMART
Calculation inputs	Submitted bids, accepted bids, market session, product, bid direction and applicable exclusions
Comparison / assessment rule	All eligible submitted bids in the assessed demonstration auction sessions

$$Bidsuccessrate = \frac{N_{accepted}}{N_{submitted}} \times 100$$

Equation 11: SI.06 calculation

Four auction sessions were executed across two demonstrations, covering two asset types (EV charging station curtailment and PV generation curtailment). By bid count, 100% of submitted bids were accepted into the clearing: all 15 bids submitted across the four sessions were admitted to the order book and selected by the pay-as-cleared merit order algorithm. Table 15 presents the per-session breakdown.

Table 15: KPI SI.06, Bid acceptance per auction session

Session	Type	Demand (kW)	Bids	Volume offered (kW)	Volume accepted (kW)
Demo 1	Upward	11	1	11	11
Demo 2.1	Downward	100	2	95	95
Demo 2.2	Downward	150	6	180	150
Demo 2.3	Downward	250	6	180	180
Total			15	466	436

By volume, 93.6% of offered flexibility was accepted (436 of 466 kW). The 30 kW not accepted in Scenario 2 was not rejected due to bid quality or eligibility, but due to the rules of the merit order clearing when supply exceeds the DSO's flexibility requirement. The algorithm accepted all lower-priced bids in full and partially filled the higher-priced bids until the required 150 kW was satisfied.

The demonstrations validated the complete technical workflow of the sMART flexibility market: congestion signal reception, auction opening, bid collection with Device Registry eligibility checks, merit order clearing with pay-as-cleared pricing, and activation signal dispatch. The three scenarios were specifically structured to exercise different clearing outcomes (balanced supply-demand, supply exceeding demand with partial acceptance, and demand exceeding supply with full acceptance), confirming that the clearing algorithm handles each case correctly.

2.2.7 SI.07 - Number of Devices Registered

Table 16: SI.07 - Number of Devices Registered — KPI definition and assessment

Item	Information
Definition	Number of flexible devices successfully registered in the Device Registry
Unit	Number
Scope	Device onboarding; related UC SI.07
STREAM tool(s)	sFLEX, Device Registry
Calculation inputs	Unique device identifiers and registration status
Comparison / assessment rule	Count of successfully registered unique devices at the reporting point

$$N_{registered} = \Sigma DevicesRegistered_i$$

Equation 12: SI.07 calculation

13 flexibility devices were successfully registered in the Device Registry across five demonstration locations.

The registered-device count demonstrates successful onboarding across multiple asset locations and provides the resource base for subsequent prequalification and market steps.

2.2.8 SI.08 - Total Nominal Capacity of Registered Devices

Table 17: SI.08 - Total Nominal Capacity of Registered Devices — KPI definition and assessment

Item	Information
Definition	Sum of the nominal capacities of all devices registered in the Device Registry
Unit	MW
Scope	registered flexibility-device population; related UC SI.07
STREAM tool(s)	sFLEX, Device Registry
Calculation inputs	Registered-device list, nominal capacity of each device and registration status
Comparison / assessment rule	Sum across the registered-device population at the reporting point

$$P_{registered,nom} = \Sigma P_{nominal,i}$$

Equation 13: SI.08 calculation

The 13 registered devices comprised nine PV devices across at Petrič, Tosla and Metal Design (0.150 MW each) and four EV charge points operated at Knauf and SloCar (0.088 MW in total), giving 0.538 MW aggregate nominal capacity [3].

The nominal-capacity result describes the technical scale of the registered demonstration population only. Available flexibility varies with operating state, resource type and service constraints, so nominal capacity must not be interpreted as continuously deliverable flexibility.

2.2.9 SI.09 - Percentage of Devices with failed Communication

Table 18: SI.09 - Percentage of Devices with failed Communication — KPI definition and assessment

Item	Information
Definition	Share of registered devices that do not acknowledge the communication test signal
Unit	%
Scope	Communication check during the prequalification workflow; related UC SI.08
STREAM tool(s)	sFLEX, Device Registry
Calculation inputs	Number of registered devices and number of devices failing the communication check
Comparison / assessment rule	All registered devices included in the communication test

$$Failedcommunication = \frac{N_{failed}}{N_{registered}} \times 100$$

Equation 14: SI.09 calculation

No communication failures were recorded among the 13 registered devices during the controlled prequalification tests: 0/13, or 0% [3]. The result covers the tested Reduxi/MQTT and AVA communication paths. The communication was checked within a defined test procedure.

The controlled result supports communication robustness for the tested devices and interfaces but does not establish long-term field availability. A later communication loss would directly reduce the pool of devices available for prequalification or activation.

2.2.10 SI.10 - Percentage of Prequalified Devices

Table 19: SI.10 - Percentage of Prequalified Devices — KPI definition and assessment

Item	Information
Definition	Share of registered devices prequalified for at least one flexibility product
Unit	%
Pilot / Scope	Slovenia – Device Registry prequalification; related UC SI.08
STREAM tool(s)	sFLEX, Device Registry
Calculation inputs	Number of registered devices and number of devices passing prequalification
Comparison / assessment rule	All registered devices submitted to the defined prequalification procedure

$$Prequalifieddevices = \frac{N_{prequalified}}{N_{registered}} \times 100$$

Equation 15: SI.10 calculation

All 13 registered devices passed the reported prequalification procedure, corresponding to a prequalification rate of 100%.

The 100% test result shows that every registered device in the reported prequalification population met the defined demonstration criteria. It is a controlled test outcome rather than a statement about an unrestricted future portfolio.

2.2.11 SI.11 - Number of Devices Prequalified

Table 20: SI.11 - Number of Devices Prequalified — KPI definition and assessment

Item	Information
Definition	Number of registered flexible devices that successfully complete prequalification
Unit	number
Scope	Device Registry prequalification; related UC SI.08
STREAM tool(s)	sFLEX, Device Registry
Calculation inputs	Unique registered-device identifiers and prequalification status
Comparison / assessment rule	Registered devices submitted to prequalification

$$N_{prequalified} = \Sigma PrequalifiedDevice_i$$

Equation 16: SI.11 calculation

13 registered flexibility devices successfully completed the prequalification procedure. This is consistent with the reported 100% prequalification rate.

2.2.12 SI.12 - Total Capacity of Prequalified Devices

Table 21: SI.12 - Total Capacity of Prequalified Devices — KPI definition and assessment

Item	Information
Definition	Sum of nominal and, where available, flexible capacity of devices that passed prequalification
Unit	MW
Scope	prequalified Device Registry population; related UC SI.08
STREAM tool(s)	sFLEX, Device Registry
Calculation inputs	Prequalified-device list and nominal/flexible capacity associated with each device
Comparison / assessment rule	Devices that successfully passed prequalification

$$P_{prequalified} = \Sigma P_{prequalified,i}$$

Equation 17: SI.12 calculation

All 13 registered devices passed prequalification [3]. Their aggregate nominal capacity is therefore the same 0.538 MW reported for SI.08. D5.1 broadens SI.12 to include flexible capacity, but it does not provide one consolidated flexible-capacity sum because prequalification setpoints depend on the momentary availability of each asset. That value is not inferred here.

For SI.12, the result defines the qualified demonstration resource base but does not state how much flexibility is available at any given time.

2.2.13 Dismissed KPIs

SI.05 (Load forecast accuracy) was originally defined to assess the accuracy of the load forecasts produced by sGRID. In the final demonstration framework, load and generation forecasting were assessed together. D5.1 therefore merged the original SI.04 (Generation forecast accuracy) and SI.05 (Load forecast accuracy) into the retained SI.04 (Load and generation forecast accuracy), covering consumption, generation and prosumer forecasts at individual-asset and aggregated transformer level. The SI.05 identifier was then reused for Grid state forecast accuracy, which assesses the end-to-end forecasted loading of the grid after the power-flow calculation. The original SI.05 is therefore not assessed separately, since its load-forecast scope is already covered by SI.04.

2.3 SPANISH TECHNICAL IMPACT

The Spanish pilot is centred on Enercoop's energy community and distribution network in Crevillent. Flexibility resources include a community PV-plus-battery installation, PV on community buildings, EV chargers, and residential prosumers with rooftop PV and batteries, while smaller consumers are aggregated within the energy community. The pilot demonstrates local flexibility-market services for DSO congestion management and voltage regulation, together with peer-to-peer exchange and coordinated operation of community assets. These services address emerging hosting-capacity constraints and voltage risks associated with increasing electrification and high local PV penetration.

The Spanish technical evaluation covers congestion forecasting and identification, potential congestion resolution, automated bidding, local energy exchange, voltage support, asset prequalification, flexibility delivery, request coverage, economic-welfare accounting and availability.

Table 22: Spanish technical KPI result

KPI ID	KPI name	Result	Unit	Assessment period / comparator
ES.02	Congestion forecast accuracy	10% threshold: 69.2%; 15%: 57.9%; 20%: 48.4%.	%	7 May-20 June 2026; Exact line/timestamp match; forced low line-capacity thresholds
ES.03	Congestion correctly identified	10% threshold: 83.2%; 15%: 79.6%; 20%: 74.9%.	%	May-June 2026; Second-method corroboration; forced low line-capacity thresholds
ES.04	Congestion resolution ratio	10% threshold: 70.9%; 15%: 56.3%; 20%: 42.5%.	%	June-July 2026; Forecast congestion events before available battery flexibility
ES.05	Correct automatic bids ratio	87.5% of eligible automatic bids were correct.	%	June-July 2026; Eligible automatic bids; manual integration tests excluded
ES.06	Local self-consumption ratio	93.6% self-consumption ratio and 41.4 MWh traded within the energy community over the considered period.	% and MWh	May-September 2025 and May-July 2026 (about 8 months); Final EnC internal-trade definition
ES.07	Reduction of voltage deviations	30.8% reduction of voltage deviations with the community battery.	%	May 2026 (no battery) vs June 2026 (with battery); EL SALÀ feeder; ±4% nominal-voltage deviation threshold
ES.08	Number of prequalified assets	20 assets were prequalified: 9 PV, 9 hybrid and 2 EV assets, grouped in 13 flexibility units.	number	Demonstration registration/prequalification; Defined asset population
ES.09	Flexibility provision compliance ratio	67.2% provision compliance on average; individual assets ranged from 36.8% to 96%.	%	June-July 2026; Committed flexibility for eligible activations
ES.11	Flexibility requests coverage	27% of total flexibility requested could be covered by the activated assets.	%	June-July 2026; Total flexibility requested
ES.13	Increase of economic welfare	3,198.72 € total increase over the considered period; average customer gain 4.56 €.	€	May-September 2025 and May-July 2026 (about 8 months); Counterfactual retailer/wholesale transaction value

ES.14	Percentage of flexibility availability	28.3% of prequalified flexibility was available on average; seven active market assets were considered, with individual availability from 7.7% to 57%.	%	June-July 2026; Prequalified/active asset capacity; minimum market capacity affects the result

2.3.1 ES.02 - Congestion forecast accuracy

Table 23: ES.02 - Congestion forecast accuracy — KPI definition and assessment

Item	Information
Definition	This KPI evaluates the percentage of times that the congestion forecast is correct.
Unit	%
Scope	EL SALÀ feeder in Crevillent; May 7th to June 20th, 2026, in hourly slots; related UC ES.01
STREAM tool(s)	sGRID
Calculation inputs	Number of congestions forecasted by sGRID, number of forecasted congestions corroborated in real time, line-capacity threshold, line and timestamp; grid_congestion_events.csv and grid_state_estimation.csv
Comparison / assessment rule	Forecast congestion events are compared with congestion events subsequently observed in real time by sGRID using exact line and timestamp matching. Forecasted congestions that triggered preventive actions are not taken into account.

$$\text{Congestion forecast accuracy} = \frac{\sum_{t \to T} C_{t,\text{ correctly forecasted}}}{\sum_{t \to T} C_{t,\text{ forecasted}}}$$

Equation 18: ES.02 - Congestion forecast accuracy calculation

- $C_{t,\text{ correctly forecasted}}$: is the number of congestions forecasted by sGRID and corroborated by the DSO.
- $C_{t,\text{ forecasted}}$: is the number of congestions forecasted by sGRID.

Results

The analysis is performed over EL SALÀ feeder in Crevillent. The period considered spans from May 7th to June 20th, 2026, in hourly slots.

The KPI is calculated by comparing forecast congestion events with congestion events subsequently observed in real time by sGRID, using exact line and timestamp matching.

The results are provided considering different thresholds of line capacity congestion. Due to the lack of observed congestions during the demonstration period, very low thresholds have been used to force the identification of events.

Table 24: ES.02 congestion forecast accuracy by line-capacity threshold

Threshold (% of line capacity)	Forecasted events	Matched events in RT	KPI
10%	24,870	17,212	69.2%
15%	14,938	8,639	57.9%
20%	9,088	4,399	48.4%

Please note: a congestion event is defined by a timestamp and a line segment, so a congestion at a given time is usually counted as multiple events.

We observe that between 48.4% and 69.2% of forecast congestions were correctly confirmed, depending on the threshold applied. The 10% threshold gives the highest accuracy because it identifies more forecast events, while the 20% threshold is more selective. As the line thresholds considered are quite low, small deviations in the forecasts impact the results of this KPI, which will not be representative in real scenarios.

2.3.2 ES.03 - Congestion correctly identified

Table 25: ES.03 - Congestion correctly identified — KPI definition and assessment

Item	Information
Definition	This KPI evaluates the percentage of times that sGRID detects a congestion in the real-time monitoring correctly.
Unit	%
Scope	EL SALÀ feeder in Crevillent; May 7th to June 20th, 2026, in hourly slots; related UC ES.01
STREAM tool(s)	sGRID
Calculation inputs	Number of congestions detected by sGRID, number corroborated by the DSO, state estimation and congestion events; grid_congestion_events.csv and grid_state_estimation.csv
Comparison / assessment rule	The state estimation of the network is used as validator. A real-time congestion event is considered correctly identified when, at the same timestamp, the maximum absolute voltage-estimation error is no greater than 0.02 p.u.

$$\text{Congestion correctly detected} = \frac{\sum_{t \to T} C_{t,\text{ correctly detected}}}{\sum_{t \to T} C_{t,\text{ detected}}}$$

Equation 19: ES.03 - Congestion correctly identified calculation

- $C_{t,\text{ correctly detected}}$: is the number of congestions detected by sGRID and corroborated by the DSO.
- $C_{t,\text{ detected}}$: is the number of congestions detected by sGRID.

Results

The analysis is performed over EL SALÀ feeder in Crevillent. The period considered spans from May 7th to June 20th, 2026, in hourly slots.

The KPI is assessed using the state estimation of the network as validator. The state estimator reconstructs the electrical state of the network from the available measurements and reports an aggregate voltage-estimation error in per-unit (p.u.) voltage. A real-time congestion event is considered correctly identified when, at the same timestamp, this maximum absolute error is no greater than 0.02 p.u., which implies that the network state used to support the detection is sufficiently accurate.

The results are provided below considering different thresholds of line capacity congestion. Due to the lack of observed congestions during the demonstration period, very low thresholds have been used to force the identification of events.

Table 26: ES.03 correctly identified congestion by line-capacity threshold

Threshold (% of line capacity)	RT events	SE-validated events	KPI
10%	38,979	32,431	83.2%
15%	24,090	19,188	79.6%
20%	13,636	10,219	74.9%

Please note: a congestion event is defined by a timestamp and a line segment, so a congestion at a given time is usually counted as multiple events.

The results are range roughly between ~75-85%, indicating high agreement between real-time congestion detections and the quality of the estimated network state at the corresponding timestamps. As the line thresholds considered are quite low, small deviations in the forecasts impact the results of this KPI, which will not be representative in real scenarios.

2.3.3 ES.04 - Congestion resolution ratio

Table 27: ES.04 - Congestion resolution ratio — KPI definition and assessment

Item	Information
Definition	This KPI evaluates the percentage of times that the activation of flexibility services solves the congestion.
Unit	%
Scope	EL SALÀ feeder in Crevillent; June 4th to July 8th, 2026, in hourly slots; related UC ES.01
STREAM tool(s)	sGRID, sMART, sFLEX, sENC
Calculation inputs	Number of resolved congestions, number of forecasted congestions and community-battery flexibility availability; grid_congestion_events.csv and market_flexibility_available.csv
Comparison / assessment rule	Only periods where the community battery had available flexibility are considered. Only forecasted congestions and their associated event time stamps that triggered flexibility services are taken into account.

$$\text{Congestion resolution ratio} = \left(\frac{N_{\text{resolved congestions}}}{N_{\text{forecasted congestions}}} \right) \times 100$$

Equation 20: ES.04 - Congestion resolution ratio calculation

- $N_{\text{resolved congestions}}$: are the congestions that have been resolved after the activation of flexibility assets.
- $N_{\text{forecasted congestions}}$: are the congestions forecasted by sGRID.

Results

The analysis is performed over EL SALÀ feeder in Crevillent. The period considered spans from June 4th to July 8th, 2026, in hourly slots.

Only the periods where the community battery had available flexibility are considered for the calculation. As the state of the community battery during the demonstration was unstable, all available flexibility is considered as potentially useful to solve congestions, regardless of whether it was activated.

Similarly to the previous KPIs, three scenarios have been analysed by considering different line loading thresholds for congestion detection. Due to the lack of observed congestions during the demonstration period, very low thresholds have been used to force the identification of events.

Table 28: ES.04 congestion resolution by line-capacity threshold

Threshold (% of line capacity)	Forecasted events	RT events	Resolved events	KPI
10%	7,269	5,152	2,117	70.9%
15%	4,498	2,532	1,966	56.3%
20%	2,758	1,172	1,586	42.5%

Please note: a congestion event is defined by a timestamp and a line segment, so a congestion at a given time is usually counted as multiple events.

The KPI shows that in most cases, the capacity of the community battery alone is not sufficient to alleviate more than 50% of the foreseen congestions in the network (especially as the threshold gets bigger).

The limited amount of flexibility available during the demonstration period (due to the low number of assets and the truncated capacity of this specific installation) result in less than half of the detected events being potentially solved through the market.

2.3.4 ES.05 - Correct automatic bids ratio

Table 29: ES.05 - Correct automatic bids ratio — KPI definition and assessment

Item	Information
Definition	This KPI evaluates the percentage of times that sENC and sFLEX automatically identifies an open DSO requirements auction and send at least one bid correctly (with the correct bid direction (sell or buy), correct zone, correct unit offer, etc.) and the bid is matched in the session.
Unit	%
Scope	Market testing periods on June 16th and July 8th, 2026; related UC ES.04
STREAM tool(s)	sENC, sFLEX and sMART
Calculation inputs	Auctions with bids matched in sMART, open auctions in sMART; market_dso_flexibility_requests.csv and market_results.csv
Comparison / assessment rule	Number of auctions with at least one correctly generated and submitted bid matched in sMART compared with the total number of open auctions.

$$\text{Correct automatic bids ratio} = \frac{\text{Auctions with bids matched in sMART}}{\text{Open auctions}} \times 100$$

Equation 21: ES.05 - Correct automatic bids ratio calculation

- **Auctions with bids matched in sMART:** are the number of auctions with at least one bid validated in sMART, correctly generated and submitted by sENC and sFLEX.
- **Open auctions:** are the number of total auctions that have been opened in sMART.

Results

The calculation is based on two testing periods where flexibility was activated through the market: June 16th and July 8th, 2026. All sessions in these two periods have been considered, even if they were later not acknowledged by the assets for activation (e.g. because the tests were over).

Table 30: ES.05 automatic bidding results

Auctions with bids matched in sMART	7
Open auctions in sMART	8
KPI	87.5%

During the considered periods, almost all sessions open by sGRID were matched with bids from sFLEX and sENC responding to the flexibility requests. Only one session on June 16th at 4 pm local time was left unmatched. This occurred because it was the third consecutive flexibility session and the community battery no longer had sufficient available flexibility to submit a valid bid. This result reflects the physical limitations of the asset rather than a malfunction of the bidding mechanism.

2.3.5 ES.06 - Local self-consumption ratio

Table 31: ES.06 - Local self-consumption ratio — KPI definition and assessment

Item	Information
Definition	For the reported calculation, the KPI is reformulated as “Energy traded inside the EnC that would have been exported/imported otherwise”.
Unit	%
Scope	May 1st to September 30th, 2025 and May 1st to July 26th, 2026; seven collective self-consumption PV installations; related UCs UC ES.06 and UC ES.07
STREAM tool(s)	sGRID, sMART, sFLEX, sENC
Calculation inputs	Energy put on sale and energy requested in the P2P market at each moment; p2p_trading.csv
Comparison / assessment rule	Energy traded inside the EnC that would have been exported/imported otherwise.

$$E_{\text{traded}} = \sum_{t} \min\left(E_{\text{ask},t}, E_{\text{bid},t}\right)$$

Equation 22: ES.06 - Local self-consumption ratio calculation

- E_{traded}: Energy traded inside the EnC that would have been exported/imported otherwise.
- E_{ask}: is the energy put on sale in the P2P market at a given moment.
- E_{bid}: is the energy requested in the P2P market at a given moment.

Results

To make it more meaningful, we have reformulated this KPI as "Energy traded inside the EnC that would have been exported/imported otherwise", with the formula:

$$E_{\text{traded}} = \sum_{t} \min\left(E_{\text{ask},t}, E_{\text{bid},t}\right)$$

Equation 23: ES.06 traded energy calculation

Where:

- E ask is the energy put on sale in the P2P market at a given moment
- E bid is the energy requested in the P2P market at a given moment

The periods considered were from May 1st to September 30th, 2025 and from May 1st to July 26th, 2026. 7 collective self-consumption PV installations were considered where, for each one, a set of EnC members have their share of the PV production, and their surplus is put in the P2P market. Analogously, the part of their consumption not covered by this share is requested to the P2P market.

Table 32: ES.06 local self-consumption results by installation

Installation	Sessions	E ask (kWh)	E bid (kWh)	E traded (kWh)	SC rate	SS rate
CEIP Escoles Noves	767	959.40	19,176.53	959.40	100%	5%
CEIP Mas Magro	2,563	6,257.19	40,843.26	6,109.60	97.64%	14.96%
CEIP Miguel Hernandez	678	509.58	21,297.04	509.58	100%	2.39%
Campo de fútbol	2,563	11,066.47	76,927.89	10,835.03	97.91%	14.08%
Museo Semana Santa	2,563	1,716.39	10,923.81	1,601.81	93.32%	14.66%
Pabellón Félix Candela	2,563	14,047.48	85,892.92	12,813.22	91.21%	14.92%
Parking Rambla	2,453	9,664.14	60,721.43	8,562.33	88.6%	14.10%
Total	14,150	44,220.65	315,782.87	41,390.97	93.6%	13.11%

The total amount of energy traded during the period (roughly 8 months) was 41.39 MWh. However, a strong consumption asymmetry is noticed: total energy requested (316 MWh) is ~7x larger than total energy on sale (44 MWh), which highlights the fact that the PV installations cover only a portion of the users' consumption and not much surplus is available (only ~14% of consumption needs can be covered by local P2P generation).

The high self-consumption rate (93.6%) shows that nearly all locally generated surplus finds a local buyer (very little is wasted to grid export), proving the usefulness of P2P markets to enhance the utilization of local generation. However, the price strategy was very simple: bid and ask prices match the average between the energy tariff and the feed-in tariff. With a more complex pricing, the number may become lower.

2.3.6 ES.07 - Reduction of voltage deviations

Table 33: ES.07 - Reduction of voltage deviations — KPI definition and assessment

Item	Information
Definition	This KPI calculates the reduction in the number of voltage deviations, comparing scenarios with the battery providing voltage conservation services with scenarios without the battery action.
Unit	%
Scope	EL SALÀ feeder in Crevillent; May 7th to May 31st, 2026 without the community battery and June 1st to June 25th, 2026 with the community battery; related UC ES.02
STREAM tool(s)	sGRID
Calculation inputs	Number of voltage deviations without the battery and with the battery; grid_voltage_deviations.csv
Comparison / assessment rule	Two periods of 25 days are compared. A voltage deviation is identified using a ±4% threshold, as established by the DSO in their daily operation.

$$\%\text{Volt_dev.red} = \frac{N_{\text{volt_devs_w/o the battery}} - N_{\text{volt_devs_w the battery}}}{N_{\text{volt_devs_w/o the battery}}} \times 100$$

Equation 24: ES.07 - Reduction of voltage deviations calculation

- $N_{\text{volt_devs_w/o the battery}}$: are the number of voltage deviations during the studied period in the scenario without the battery.
- $N_{\text{volt_devs_w the battery}}$: are the number of voltage deviations during the studied period in the scenario with the battery.

Results

The analysis is performed over EL SALÀ feeder in Crevillent. The KPI compares two periods of 25 days:

- No community battery: May 7th to May 31st, 2026
- With community battery: June 1st to June 25th, 2026

The threshold to consider a voltage deviation is ±4%, as established by the DSO in their daily operation. Depending on the type of bus:

Table 34: ES.07 voltage limits by bus type

Bus type	Count	Nominal voltage	Allowed voltage range
3-phase line-to-line	309	400 V	384–416 V
Single-phase	7	230 V	220.8–239.2 V

The results were:

Table 35: ES.07 voltage-deviation reduction

Number of events without battery	32,853
Number of events with battery	22,730
KPI	30.81%

The community battery reduced voltage deviations by ~31% in June when comparing it with the period when the battery was not working in May. This result was expected: fewer buses exceeding the 4% operational band when the battery is active, as the battery is absorbing excess PV generation and reducing local voltages.

It should be noted that, during the reference period in which the community battery was not operational, the PV installation associated with the battery was curtailed in order to avoid voltage deviations. Consequently, the reported 31% reduction represents a conservative estimate of the battery's impact, as a larger number of voltage deviations would likely have occurred in the absence of both the battery and the PV generation limitation.

It was also noticed that the same set of 21 buses were affected in both periods, so the battery reduces the frequency and duration of the events but cannot eliminate them entirely. Moreover, all events observed during both periods were over-voltages, but none of them exceeded the regulatory limit of 10% as legally established Spain (UNE-EN 50160).

2.3.7 ES.08 - Number of prequalified assets

Table 36: ES.08 - Number of prequalified assets — KPI definition and assessment

Item	Information
Definition	This KPI shows the number of assets that have been prequalified in the local flexibility market
Unit	/
Scope	Main set of Spanish pilot demonstrations; related UC ES.03
STREAM tool(s)	sMART
Calculation inputs	Number of prequalified assets in sMART; market_prequalified_assets.csv
Comparison assessment rule /	Count of assets prequalified in sMART for the main set of demonstrations.

$$N_{\text{prequalified assets in sMART}}$$

Equation 25: ES.08 - Number of prequalified assets calculation

- $N_{\text{prequalified assets in sMART}}$: is the number of prequalifed assets in sMART.

Results

The number of assets prequalified for the main set of demonstrations were 20, grouped in 13 flex units:

Table 37: ES.08 prequalified assets

Asset	Type	Capacity (MW)	Flex. unit
Campo de fútbol	Solar photovoltaic	0.10	CAMFU
CEIP Mas Magro	Solar photovoltaic	0.10	CEIP
COMPTEM User 1	Hybrid	0.01	COMPT
COMPTEM User 2	Hybrid	0.01	COMPT
COMPTEM User 3	Hybrid	0.01	COMPT
COMPTEM User 4	Hybrid	0.01	COMPT
COMPTEM User 5	Hybrid	0.01	COMPT
COMPTEM User 6	Hybrid	0.01	COMPT
COMPTEM User 7	Hybrid	0.01	COMPT
COMPTEM User 10	Hybrid	0.01	COMPT
CEIP Escoles Noves	Solar photovoltaic	0.08	ESNOV
EV Nave	Electric vehicle	0.01	EVNAV
EV Oficina	Electric vehicle	0.01	EVOFI
Community battery + PV	Hybrid	0.10	MERLO
CEIP Miguel Hernandez	Solar photovoltaic	0.09	MIHER
Museo Semana Santa	Solar photovoltaic	0.01	MUSEO
Pabellón Félix Candela	Solar photovoltaic	0.05	PABEL
Parking Rambla	Solar photovoltaic	0.05	PARK
Parc nou	Solar photovoltaic	0.05	PARNO
CEIP Pilar Ruiz	Solar photovoltaic	0.10	PIRUI

The prequalification of the assets directly controlled by the tools (sFLEX, sENC) was accompanied by the corresponding technical tests to assess the validity of the capacity registered. However, in some cases, the actual capacity of the asset was lower than the minimum capacity forced by market restrictions (0.01 MW), but a decision was taken to register them anyway not to shorten the list of available elements in sMART.

2.3.8 ES.09 - Flexibility provision compliance ratio

Table 38: ES.09 - Flexibility provision compliance ratio — KPI definition and assessment

Item	Information
Definition	This KPI measures the extent to which the flexibility assets fulfil their flexibility commitments resulting from the market clearing process. It is calculated as the ratio between the flexibility actually delivered and the flexibility committed in the market.
Unit	%
Scope	Two testing periods where flexibility was activated through the market during June and July 2026; related UCs UC ES.01, UC ES.02 and UC ES.04
STREAM tool(s)	sFLEX, sENC, sMART, sGRID
Calculation inputs	Flexibility actually provided by the asset and flexibility committed as a result of the market auctions; market_flexibility_delivered.csv
Comparison / assessment rule	Flexibility actually provided is compared with the flexibility committed in the market. Results from manual tests around the testing periods are excluded.

$$\text{Flexibility compliance} = \frac{F_{\text{provided}}}{F_{\text{committed}}}$$

Equation 26: ES.09 - Flexibility provision compliance ratio calculation

- F_{provided}: the flexibility actually provided by the asset (forecasted consumption/generation minus the actual consumption/generation).
- $F_{\text{committed}}$: flexibility that the assets are committed to provide as a result of the market auctions.

Results

The calculation is based on two testing periods where flexibility was activated through the market during June and July 2026. The results from manual tests around those periods are excluded to avoid distortion in the KPI results.

The results were:

Table 39: ES.09 flexibility provision compliance by market unit

Market unit	Flex. committed (MWh)	Flex. provided (MWh)	KPI
CAMFU	0.1900	0.1786	94.00%
MERLO	0.1200	0.1152	96.00%
PABEL	0.2400	0.1275	53.12%
PARK	0.1700	0.0625	36.76%
Total	0.7200	0.4838	67.19%

The results show that, on average, assets were able to deliver more than half the flexibility committed in the market. This behaviour could be fine-tuned by better adjusting the prevision of flexibility, which sometimes can lose accuracy by not considering fine-grained fluctuations (e.g. forecasts are calculated per hour or 15-minutes while the setpoint of the inverters can change several times per minute). Nevertheless, the result would be to commit less flexibility to the market—as opposed to increase the flexibility provided—as all available flexibility was activated in all cases.

2.3.9 ES.11 - Flexibility requests coverage

Table 40: ES.11 - Flexibility requests coverage — KPI definition and assessment

Item	Information
Definition	This KPI measures the flexibility energy requested by the DSO covered by the FSPs.
Unit	%
Scope	Two testing periods where flexibility was activated through the market during June and July 2026; related UC ES.04
STREAM tool(s)	sGRID, sFLEX, sENC, sMART
Calculation inputs	Energy activated during period $\boldsymbol{t}$, energy requested by the DSO during period $\boldsymbol{t}$; market_dso_flexibility_requests.csv and market_flexibility_delivered.csv
Comparison / assessment rule	The energy provided considers just the energy that has been effectively provided by the FSPs, not the energy matched in the local flexibility market. Results from manual tests around the testing periods are excluded.

$$\text{Flexibility requests coverage} = \frac{\sum_t E_{t,\,\text{provided}}}{\sum_t E_{t,\,\text{requested}}} \times 100$$

Equation 27: ES.11 - Flexibility requests coverage calculation

- $E_{t,\,\text{provided}}$: is the energy activated during the period t.
- $E_{t,\,\text{requested}}$: is the energy requested by the DSO during the period t.

Results

The calculation is based on two testing periods where flexibility was activated through the market during June and July 2026. The results from manual tests around those periods are excluded to avoid distortion in the KPI results.

The results were:

Table 41: ES.11 flexibility request coverage by market unit

Market unit	Flex. requested (MWh)	Flex. provided (MWh)	KPI
CAMFU	0.4270	0.1786	41.83%
MERLO	0.3271	0.1152	35.21%
PABEL	0.6043	0.1275	21.10%
PARK	0.4317	0.0625	14.48%
Total	1.7900	0.4838	27.03%

The results highlight the low number of assets in the demonstration and their limited capacity, not only nominal but also in operation, as none of them were fully dedicated to providing services to the market.

2.3.10 ES.13 - Increase of economic welfare

Table 42: ES.13 - Increase of economic welfare — KPI definition and assessment

Item	Information
Definition	This KPI measures, in a peer-to-peer energy operation, the increase of economic welfare comparing the costs/gains of this operation to buying/selling this energy to their retailer.
Unit	€
Scope	May 1st to September 30th, 2025 and May 1st to July 26th, 2026; seven collective self-consumption PV installations; related UC ES.06
STREAM tool(s)	sFLEX, sENC, sMART
Calculation inputs	Energy exchanged between energy-community peers, retailer price, peer-operation price and wholesale-market selling price; p2p_trading.csv
Comparison / assessment rule	The price of the operation between peers is set between the wholesale-market price and the retailer price. In the case of avoiding an energy curtailment of the producer by using this method, the price of the wholesale market is 0.

Increase of economic welfare

$$= \sum_{t} E_{t,\,\text{peers operation}} \left[\left(P_{\text{retailer}} - P_{\text{peers operation}} \right) + \left(P_{\text{peers operation}} - P_{\text{wholesale market}} \right) \right]$$

Equation 28: ES.13 - Increase of economic welfare calculation

- $E_{t,\,\text{peers operation}}$: is the energy exchanged between energy community peers through the local market.
- P_{retailer}: is the price the consumer would have to pay to its retailer.
- $P_{\text{peers operation}}$: is the price of the operation between peers.
- $P_{\text{wholesale market}}$: is the selling price in the wholesale market.

Results

The periods considered were from May 1st to September 30th, 2025 and from May 1st to July 26th, 2026. 7 collective self-consumption PV installations were considered where, for each one, a set of EnC members have their share of the PV production, and their surplus is put in the P2P market. Analogously, the part of their consumption not covered by this share is requested to the P2P market.

Table 43: ES.13 economic welfare by installation

Installation	Associated users	Sessions	E traded (kWh)	Welfare (€)	Welfare per user (€)
CEIP Escoles Noves	94	767	959.40	65.85	0.70
CEIP Mas Magro	79	2,563	6,109.60	484.23	6.13
CEIP Miguel Hernandez	121	678	509.58	35.07	0.29
Campo de fútbol	133	2,563	10,835.03	822.74	6.19
Museo Semana Santa	20	2,563	1,601.81	124.01	6.20
Pabellón Félix Candela	143	2,563	12,813.22	1,009.30	7.06
Parking Rambla	113	2,453	8,562.33	657.52	5.82
Total	702	14,150	41,390.97	3,198.72	4.56

The total welfare during the period (roughly 8 months) was 3,198.72 €. Pabellón Félix Candela achieves the highest welfare per customer (7.06 €) with the largest traded volume, followed by Campo de Fútbol (6.19 €). Museo Semana Santa achieves 6.20 €/customer with only 20 customers, which showcases high efficiency per member despite its small size.

CEIP Miguel Hernandez has the lowest welfare per customer (0.29 €) followed by CEIP Escoles Noves, but in these two cases only the 2026 period is considered (as they were late integrations into sENC). With equal periods, their figures would likely increase.

Although the economic benefit obtained per customer is relatively modest, the results demonstrate that local peer-to-peer trading can generate measurable economic value without requiring any active participation from the end users. Once the market mechanisms are configured, the optimization and trading processes are carried out automatically, allowing community members to benefit from improved energy management without modifying their behaviour or interacting with the market.

2.3.11 ES.14 - Percentage of flexibility availability

Table 44: ES.14 - Percentage of flexibility availability — KPI definition and assessment

Item	Information
Definition	This KPI evaluates the flexibility capacity relative to the total installed power capacity in the grid.
Unit	%
Scope	Seven assets registered in sMART; June 5th to July 8th, 2026, in hourly slots; related UC ES.04
STREAM tool(s)	sGRID, sFLEX, sENC
Calculation inputs	Number of installations, available flexibility capacity of each installation and total capacity of each asset; market_prequalified_assets.csv and market_flexibility_available.csv
Comparison / assessment rule	For each hourly slot, available upper and lower flexibility is compared with the pre-qualified capacity in the market. For PV installations, periods with no PV production are excluded.

$$\text{Percentage of flexibility availability} = \frac{\sum_{i}^{n} P_{i,\text{flex}}}{\sum_{i=1}^{n} P_i} \times 100$$

Equation 29: ES.14 - Percentage of flexibility availability calculation

- n: is the number of installations of the grid.
- $P_{i,\text{flex}}$: is the amount of flexibility capacity available at a given moment of the installation i.
- P_i: is the total capacity of the asset i.

Results

The KPI is calculated over 7 of the assets registered in sMART:

Table 45: ES.14 assets included in the flexibility-availability assessment

Asset ID	Type	Capacity (MW)
MERLO	Hybrid	0.1
COMPT	Hybrid (aggregated)	0.08 (8 x 0.01)
CAMFU	PV	0.1
CEIP	PV	0.1
MUSEO	PV	0.01
PABEL	PV	0.05
PARK	PV	0.05

Total	0.49

The considered period spans from June 5th to July 8th, 2026, in hourly slots. For each slot, the upper flexibility (all assets) and lower flexibility (hybrid assets only) available is calculated. Values are compared to the pre-qualified capacity in the market. For PV installations, periods with no PV production (typically night hours) have been excluded to avoid deflating the KPI artificially.

Table 46: ES.14 flexibility availability by asset

Asset ID	Lower flex.	Upper flex.	Overall flex.
MERLO	24.13%	32.91%	57.04%
COMPT	5.46%	4.78%	10.24%
CAMFU	-	20.66%	20.66%
CEIP	-	7.73%	7.73%
MUSEO	-	22.25%	22.25%
PABEL	-	50.54%	50.54%
PARK	-	35.69%	35.69%
Total	5.80%	22.55%	28.35%

The results showcase two factors inherent to the tests performed:

- The minimum capacity to pre-qualify an asset in the market is 0.01 MW (10 kW), which some installations hardly cover.
- Flexibility provided to the market is generally calculated based on the surplus of the installations (specially for pure PV ones), which generally is not much as they are sized to the purpose they serve. Furthermore, the flexibility available from PV assets is inherently linked to their generation profile, resulting in reduced flexibility during ramp-up, ramp-down and non-peak generation periods. These installations cannot provide more flexibility to the market without impacting their associated customers.

2.3.12 Dismissed KPIs

ES.01 (Reduction of congestions frequency) was originally defined to assess the reduction in the number of congestion events after the implementation of sGRID. However, no real congestion occurred in the pilot network during the demonstration. Congestion-management functionalities were instead tested by creating controlled scenarios with reduced network-capacity limits. These scenarios allow congestion forecasting, identification and potential resolution to be assessed through ES.02, ES.03 and ES.04, but they do not provide the real before-and-after congestion frequency required for ES.01. D5.1 therefore removed ES.01 from the final KPI set.

ES.10 (Trustful bids percentage) was intended to measure the percentage of matched flexibility offers that were not blocked by sGRID. During the revision of the demonstration KPIs, this indicator was considered to overlap with ES.05 (Correct automatic bids ratio). The updated ES.05 assesses whether sENC and sFLEX correctly identify an open DSO requirement session and submit correctly generated bids that are validated in sMART. The validity of the automated bidding process is therefore already assessed through ES.05, and D5.1 removed ES.10 as a separate KPI.

ES.12 (Flexibility delivery precision) was originally defined to measure under-delivery by comparing the flexibility delivered by an asset with the flexibility offered in its bid. In the final KPI framework, this information is covered by the updated ES.09 (Flexibility provision compliance ratio), which compares the flexibility actually provided with the flexibility committed through the market-clearing process. Both indicators therefore assess whether cleared flexibility is delivered as committed. D5.1 identified this overlap and removed ES.12 as a separate KPI.

2.4 ITALIAN TECHNICAL IMPACT

The Italian pilot is located in Terni and is operated by ASM Terni, whose multi-utility activities link the electricity distribution network with water services and other municipal energy assets. The pilot demonstrates DSO flexibility-request, bidding, activation and remuneration workflows, while also assessing load shifting in water pumping and coordinated scheduling of distributed flexibility to support grid operation, renewable-energy use and cross-sector interaction between electricity, water and electric mobility.

Table 47: Italian technical KPI results

KPI ID	KPI name	Result	Unit	Assessment period / comparator
IT.02	Response to flexibility request	Workflow demonstrated end-to-end; consolidated activation and energy-coverage totals not recorded	-	the set of eligible requests and required flexibility in the assessed sessions
IT.03	Share of users with detectable HVAC flexibility	29 of 41 valid meters (approximately 71%) showed detectable temperature-dependent electricity consumption.	%	Residential HVAC analysis period in D5.1
IT.04	Increase in local renewable energy self-consumption	Baseline PV used for pumping: 2,367.69 kWh; PV-aware schedule: 3,200.81 kWh; increase: 833.13 kWh (35.2%).	%	Representative day, May 2026
IT.05	Accuracy of transformer loading forecast	Monthly WMAPE ranged from 11.19% to 19.63%; MAPE ranged from 11.68% to 22.88%.	%	July 2025-May 2026
IT.06	Number of registered flexibility providers	1 flexibility provider (EMOT) registered and available for flexibility-market participation.	number	provider population before onboarding or the defined demonstration starting point
IT.07	Accuracy of grid reconstruction	Average percentage error 2.78%; maximum percentage error 13.12%.	%	Grid-reconstruction validation in the demonstration period

2.4.1 IT.02 - Response to flexibility request

Table 48: IT.02 - Response to flexibility request — KPI definition and assessment

Item	Information
Definition	Technical response of registered providers/assets to an issued flexibility request, expressed through activation and energy-coverage measures.
Unit	%
Scope	Registered providers/assets responding to flexibility requests; related UCs IT.03 and IT.08.
STREAM tool(s)	sMART
Calculation inputs	Eligible requests, responding activations, and required/provided flexibility-energy totals.
Comparison / assessment rule	Eligible requests and required flexibility in the assessed sessions. The complete totals needed for a consolidated activation rate or energy-coverage percentage are not reported.

$$Activationrate = \frac{N_{provided}}{N_{requested}} \times 100$$

Equation 30: IT.02 calculation

Result: the flexibility-request workflow was executed end-to-end in the Italian demonstration: requests issued by the DSO through sMART were received by EMOT acting as CPO, bids were submitted and accepted, charging schedules were adapted within the requested activation window, and the delivered flexibility was subsequently validated and remunerated (test cases IT-UC.03.02 and IT-UC.08.01). Consolidated totals for eligible requests, responding activations and required versus provided flexibility energy were not recorded during the demonstration; a consolidated activation rate and energy-coverage percentage are therefore not reported.

IT.02 confirms the operational responsiveness of the registered provider to DSO flexibility requests but does not establish a quantified response performance. As no real congestion events occurred in the pilot grid — the reason for which IT.01 was dismissed — the activations were carried out under controlled demonstration conditions, and any ratio derived from them would characterise the demonstration protocol rather than provider performance under operational congestion.

2.4.2 IT.03 - Share of users with detectable HVAC flexibility

Table 49: IT.03 - Share of users with detectable HVAC flexibility — KPI definition and assessment

Item	Information
Definition	Share of valid residential meters whose consumption shows detectable temperature-dependent HVAC behaviour.
Unit	%
Scope	Residential HVAC analysis; related UC IT.05.
STREAM tool(s)	sFLEX
Calculation inputs	Valid smart-meter series, temperature data, data-quality screening and HVAC-behaviour classification.
Comparison / assessment rule	All 41 meters retained after data-quality screening.

Result: 29 of 41 valid meters (approximately 71%) showed detectable temperature-dependent electricity consumption.

$$\alpha_{HVAC} = \frac{N_{HVAC}}{N_{valid}}$$

Equation 31: IT.03 calculation

Detectable temperature dependence in 29 of 41 valid meters supports a sizeable screening pool for further flexibility assessment, but it is not itself a measure of dispatchable or user-accepted flexibility.

2.4.3 IT.04 - Increase in local renewable energy self-consumption

Table 50: IT.04 - Increase in local renewable energy self-consumption — KPI definition and assessment

Item	Information
Definition	Relative increase in locally generated PV energy used by water-pump operation under the PV-aware optimised schedule compared with the baseline schedule.
Unit	%
Scope	Water-pump operation for the same representative day; related UCs IT.04 and IT.06.
STREAM tool(s)	sENC
Calculation inputs	Baseline and optimised pump schedules, PV generation and PV energy used for pumping for the same representative day.
Comparison / assessment rule	Baseline pump schedule without PV-aware self-consumption optimisation.

Result: Baseline PV used for pumping: 2,367.69 kWh; PV-aware schedule: 3,200.81 kWh; increase: 833.13 kWh (35.2%).

$$\Delta SC = \frac{W_{PV}^{OPT} - W_{PV}^{BASE}}{W_{PV}^{BASE}}$$

Equation 32: IT.04 calculation

PV-aware scheduling increased locally generated PV energy used by pumping by 35.2% for the representative day. This is a validated optimisation/model result for that day, not an annual measured environmental impact.

2.4.4 IT.05 - Accuracy of transformer loading forecast

Table 51: IT.05 - Accuracy of transformer loading forecast — KPI definition and assessment

Item	Information
Definition	Forecast error of transformer loading relative to measured transformer loading over matched forecast windows.
Unit	%
Scope	Transformer-loading forecast over matched windows; related UC IT.02.
STREAM tool(s)	sGRID
Calculation inputs	Measured and forecast transformer loading, matched timestamps, forecast horizon/model version and quality exclusions.
Comparison / assessment rule	Measured transformer loading over the matched windows.

Result: Monthly WMAPE ranged from 11.19% to 19.63%; MAPE ranged from 11.68% to 22.88%.

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\frac{p_t^{act} - p_t^{for}}{p_t^{act}} \times 100\%$$

Equation 33: IT.05 MAPE calculation

$$WMAPE = \frac{\sum_{t=1}^{n} p_t^{act} - p_t^{for}}{\sum_{t=1}^{n} p_t^{act}} \times 100\%$$

Equation 34: IT.05 WMAPE calculation

Forecast error varies materially by month, so the result is best interpreted as a performance range rather than a single universal forecast-accuracy value. The period also contained no real transformer congestion.

2.4.5 IT.06 – Number of registered flexibility providers

Table 52: IT.06 - Number of registered flexibility providers — KPI definition and assessment

Item	Information
Definition	Number of unique flexibility providers successfully registered in the Italian STREAM marketplace.
Unit	number
Scope	Italian STREAM marketplace registration; related UC IT.03.
STREAM tool(s)	sMART
Calculation inputs	Number of unique flexibility providers successfully registered on the marketplace.
Comparison / assessment rule	Count of unique flexibility providers successfully registered on the marketplace.

Result: one flexibility provider (EMOT) was registered and subsequently participated in the demonstrated Italian marketplace workflow.

Equation 35: IT.06 Calculation

$$N_{registered}providers = \Sigma RegisteredProvider_i$$

where $RegisteredProvider$ is the number of unique flexibility providers successfully registered on the marketplace.

The result is supported by test case IT-UC.03.01, where EMOT, acting as Charging Point Operator (CPO), completed the registration workflow for its EV charging assets. The DSO verified the submitted information, the charging stations were registered with dedicated asset profiles, and the registered assets became available within the flexibility platform. The subsequent flexibility mobilisation test identifies EMOT as both flexibility provider and aggregator, confirming that the registered provider was able to proceed from registration to participation in the marketplace workflow.

2.4.6 IT.07 - Accuracy of grid reconstruction

Table 53: IT.07 - Accuracy of grid reconstruction — KPI definition and assessment

Item	Information
Definition	Percentage error between reconstructed grid parameters and the reference representation used to validate the Italian grid reconstruction.
Unit	%
Scope	Italian grid reconstruction validation; related UC IT.01.
STREAM tool(s)	sGRID
Calculation inputs	Reconstructed and reference impedance/grid-parameter values, measurement points, model configuration and known/missing topology information.
Comparison / assessment rule	Reference matrix/grid representation used for the validation.

Result: Average percentage error 2.78%; maximum percentage error 13.12%.

$$PE = \frac{Z_{calc} - Z_{meas}}{Z_{meas}} \times 100$$

Equation 36: IT.07 calculation

The low average value of the KPI supports the model as a usable representation for the tested workflow while retaining element-level uncertainty and the documented limitations in grid input information.

2.4.7 KPIs Dismissed

IT.01 (Reduction of congestions) was originally defined to assess the percentage of forecasted congestion cases that were avoided through flexibility activation. During the Italian demonstration, no real congestion events occurred in the grid. As the required congestion events were not available for the planned comparison, D5.1 removed IT.01 from the final KPI set.

2.5 FINNISH TECHNICAL IMPACT

The Finnish pilot uses OptiWatti-managed residential buildings and holiday-resort buildings to test explicit demand response from electric radiators and electric floor heating. Room-level controls and customer settings are used to estimate and aggregate available heating flexibility while maintaining acceptable indoor conditions. The demonstrated service is Frequency Containment Reserve for Disturbances (FCR-D), with both upward and downward regulation achieved by rapidly reducing or increasing heating load in response to grid-frequency deviations. The pilot therefore evaluates how aggregated residential demand can support TSO frequency stability alongside existing energy-management and spot-price optimisation functions.

The Finnish technical evaluation concerns aggregated electric-heating flexibility for FCR-D services using sFLEX and sDATA. Bid data and one-second FCR logs provide the calculation inputs; FI.05 is explicitly simulation/estimation based because the live TSO connection was not part of the prioritised demonstration scope [3]. Technical impact analysis of FI.01 and FI.02 incorporate two sets of logs - first set includes real-load pilot observations and bidding logs for time period of 2 weeks with limited flexibility participation. Second set consists of simulated scaled FCR and bidding logs for 24 hours.

Table 54: Finnish technical KPI result status

KPI ID	KPI name	Result	Unit	Assessment period / comparator
FI.01	FCR activation speed	FCR-D-up simulated scaled logs compliance triplet =(0,0,0), overall = 0% FCR-D-down simulated scaled logs compliance triplet = (100,100,100), overall = 100%	service-specific compliance triplet and overall compliance	required proportional response defined by the FCR-D activation curve for each eligible event
FI.02	Flexibility estimation accuracy	Estimation ratio = 82.3% and estimation error = 16.3 % in simulated scaled FCR-D-down logs	%	reserved flexible power for the same hour and service direction
FI.05	Bid acceptance rate	>90% of bid offered	%	offered power for the same hour and service direction

2.5.1 FI.01 - FCR activation speed

Table 55: FI.01 - FCR activation speed — KPI definition and assessment

Item	Information
Definition	Compliance of FCR-D-up and FCR-D-down response with 50% activation after 5 seconds, 86% after 7.5 seconds and 100% after 30 seconds.
Unit	Service-specific compliance triplet and aggregated overall compliance.
Scope	FCR-D-up and FCR-D-down assessed separately; associated with FI.01.
STREAM tool(s)	sFLEX, sDATA
Calculation inputs	One-second FCR logs, maintained capacity, control output signal, activated flexible power, service direction and eligible full-activation events.
Comparison / assessment rule	Required proportional response defined by the FCR-D activation curve for each eligible event. The 86% criterion uses 8 seconds because the logs have one-second intervals.

$$Compliance_t = \begin{cases} 1 \; if \; Act_t \geq required \; fraction \times Cap \times ContOutSig \\ 0 \; otherwise \end{cases}$$

Equation 37: FI.01 calculation

FCR logs samples at one-second interval, thus 86% criterion uses 8 seconds in assessment. FI.01 is calculated separately for both FCR-D-down and FCR-D-up market. FCR-D-up logs record 84 successful activation requests, 42 among these last for five seconds or more, 31 last over eight seconds and 7 crosses over thirty second mark. FCR-D-up activation speed achieves success in complying 41% of activation requests. Similarly, FCR-D-down market for real-load pilot observation logs consist of a total of 394 activation requests out of which 236 cross five seconds mark, 190 cross eight second mark and 51 last for thirty seconds or more. FCR-D-down activation speed achieves an overall success rate of 42%.

FCR-D-up simulated scaled logs observe 3 activation requests, 2 among those cross five seconds mark, 1 cross eight seconds mark and 1 complete thirty seconds mark but it did not achieve any success in complying any of the activation requests. Contrary to FCR-D-up, FCR-D-down market simulated scaled logs observe 10 activation requests, out of which 3 complete five seconds mark, 2 cross eight seconds mark and 1 last for thirty seconds or more. This set of logs achieve 100% success in complying to activation requests.

Table 56: FI.01 for real flexibility logs

FI.01	Activation level	Time duration (in seconds)	activation request crossing time duration	Successful activation achieved	% activation success	overall % percent
FCR-D-up market	50% activation	5	42	15	35%	41%
	86% activation	8	31	13	41%	
	100% activation	30	7	5	71%	
FCR-D-up simulated scaled logs	50% activation	5	2	0	0%	0%
	86% activation	8	1	0	0%	
	100% activation	30	1	0	0%	
FCR-D-down market	50% activation	5	236	105	44%	42%
	86% activation	8	190	71	37%	
	100% activation	30	51	27	52%	
FCR-D-down simulated scaled logs	50% activation	5	3	3	100%	100%
	86% activation	8	2	2	100%	
	100% activation	30	1	1	100%	

In both market-types real-load pilot observation logs show partial success in fulfilling activation requests that lasted the minimum duration mark. However, the simulated scaled logs depict contrary results among markets. FCR-D-up scaled logs fail to fulfil any activation request, however FCR-D-down scaled logs show successful compliance of all sustained activation requests. These results show the high potential for improvement in the electric heating device management process and algorithm. Since simulated scaled logs consist of one day logs only, therefore it cannot establish the process efficiency confidently or any improvement in process or algorithm among two observations duration.

2.5.2 FI.02 - Flexibility estimation ratio

Table 57: FI.02 - Flexibility estimation ratio — KPI definition and assessment

Item	Information
Definition	Bias in the algorithmic estimate of power availability at the bid stage, measured as the ratio of offered bid power to available aggregated power.
Unit	%
Scope	FCR-D-up and FCR-D-down assessed separately, using real-load pilot observations and simulated scaled logs; associated with FI.01.
STREAM tool(s)	sFLEX, sDATA
Calculation inputs	Hourly offered bid power and available power derived from one-second FCR logs, aggregated to the corresponding service hour.
Comparison / assessment rule	Available flexible power for the same hour and service direction. Ratios above 100% indicate overestimation at the bid stage.

$$Flexibility\ estimation\ ratio = \frac{P_{offered}}{P_{available}} \times 100$$

Equation 38: FI.02 calculation

FI.02 shows the direction of estimation bias at the bid stage. An auxiliary diagnostic, the flexibility-estimation error, measures the magnitude of that bias as the absolute difference between offered and available power divided by available power. It uses the same bid and FCR-log inputs but is not a separate replacement KPI.

$$Flexibility\ estimation\ error = \frac{|P_{offered} - P_{available}|}{P_{available}} \times 100$$

Equation 39: FI.02 auxiliary flexibility-estimation error

FI.02 is calculated for two evidence sets: real-load pilot observations with limited flexibility participation and simulated scaled logs. Offered power is sampled hourly. Available power is derived from one-second FCR logs and aggregated to the corresponding service hour.

For the real-load dataset, both FCR-D-down and FCR-D-up show a flexibility estimation ratio above 100% for most observed hours, indicating overestimation at the bid stage. Spikes, missing values and occasional collapse to zero also show data-recording inconsistency. For FCR-D-down, the mean auxiliary estimation error is 41.1%, with minimum 0%, maximum 549.9% and standard deviation 86.8%.

For FCR-D-up, the mean auxiliary estimation error is 318.8%, with minimum 82.4%, maximum 2689.4% and standard deviation 335.6%. The high percentage errors are amplified by the small absolute power

values in the real-load pilot: maximum offered power was 48.1 kW for FCR-D-down and 4.0 kW for FCR-D-up, while available power reached 33 kW and 1.71 kW, respectively. Missing values in some FCR logs cause sudden power changes and further increase error variability.

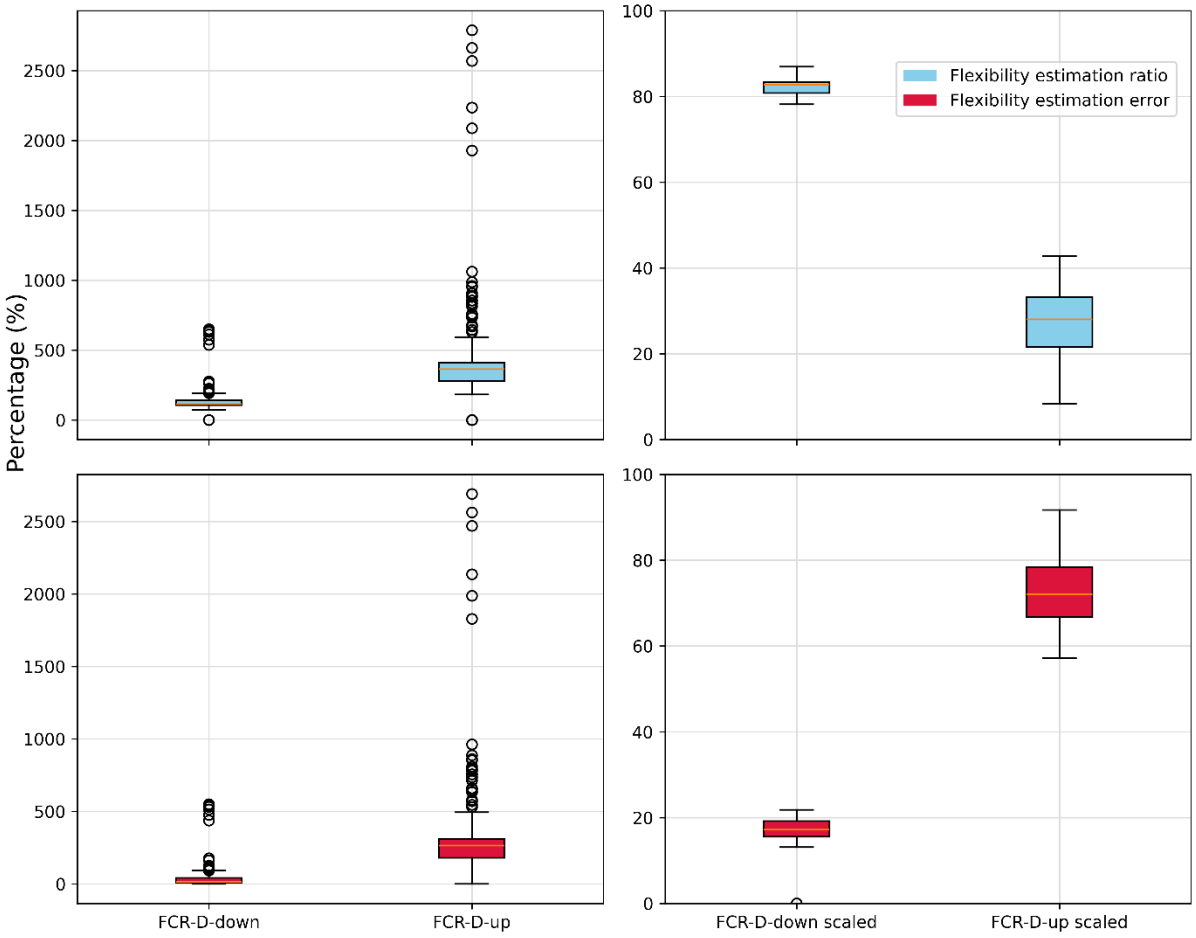


Figure 3: FI.02

Similarly, flexibility estimation ratio plot analysis for simulated scaled logs show value lower than 100% for entire simulated duration, implying conservative estimation in offered power at bid-estimation. Contrast to real-load FCR logs, simulated logs in FCR-D-down market show reduced error in flexibility estimation, an average of 16.3%, minimum, maximum and standard deviation of 13.1%, 21.8% and 5.4%. Simulated logs of FCR-D-up market also depicts reduction in flexibility estimation error, 73.2% average, 57.2% minimum, 91.7% maximum and standard deviation of 9.3%.

An improvement at bid estimation by the forecasting algorithm and more conservative bids in the simulated case were observed compared to the higher aggregated power change overestimation in the older real-load case. This reduces financial implications from mismatch between offered and available power. The error in FCR-D-down market is considerably low compared to FCR-D-up market, therefore highlighting the potential of improvement in forecasting algorithm.

Table 58: Flexibility estimation error

KPI		FCR-D-up				FCR-D-down			
		Real logs	Remark	Scaled logs	Remark	Real logs	Remark	Scaled logs	Remark
Flexibility estimation error	Mean	318.3 %	Overestimation according to flexibility estimation ratio	73.2 %	Conservative estimation according to flexibility estimation ratio	41.1 %	Overestimation according to flexibility estimation ratio	16.3 %	Conservative estimation according to flexibility estimation ratio
	std	335.6 %		9.3 %		86.8 %		5.4 %	
	Min	82.4%		57.2 %		0%		13.1 %	
	Max	2689.4%		91.7 %		549.9%		21.8 %	

Flexibility utilization is a supporting indicator of flexibility estimation accuracy and measures the extent of available power used as maintained power for flexibility. It is mathematically denoted as ratio between maintained power and available power, calculated separately for both FCR-D-up and FCR-D-down market. The unit is % and it is associated with FI.01 and extension of FI.02. sFLEX and sDATA are the applicable STREAM tools. The calculation uses available power and maintained power retrieved from FCR logs recorded at one-second interval and aggregated to hourly scale for same service.

$$Flexibility\ utilization = \frac{P_{maintained}}{P_{available}} \times 100$$

Equation 40: Flexibility utilization

Flexibility utilization uses same two sets of FCR logs as used in flexibility estimation ratio and error. Real-load FCR-D-down logs show 99% of available power used as maintained power on an average basis with minimum, maximum and standard deviation of 74%, 100% and 9%. Similarly, FCR-D-up market depicts similar power utilization i.e. 97% average, 99% minimum, 100% maximum and standard deviation of 16%. High flexibility utilization would indicate that the devices were used effectively and in a controlled manner to match the maintained power to the available power. However, due to inconsistencies in data recording, this conclusion cannot be fully confirmed from these observations.

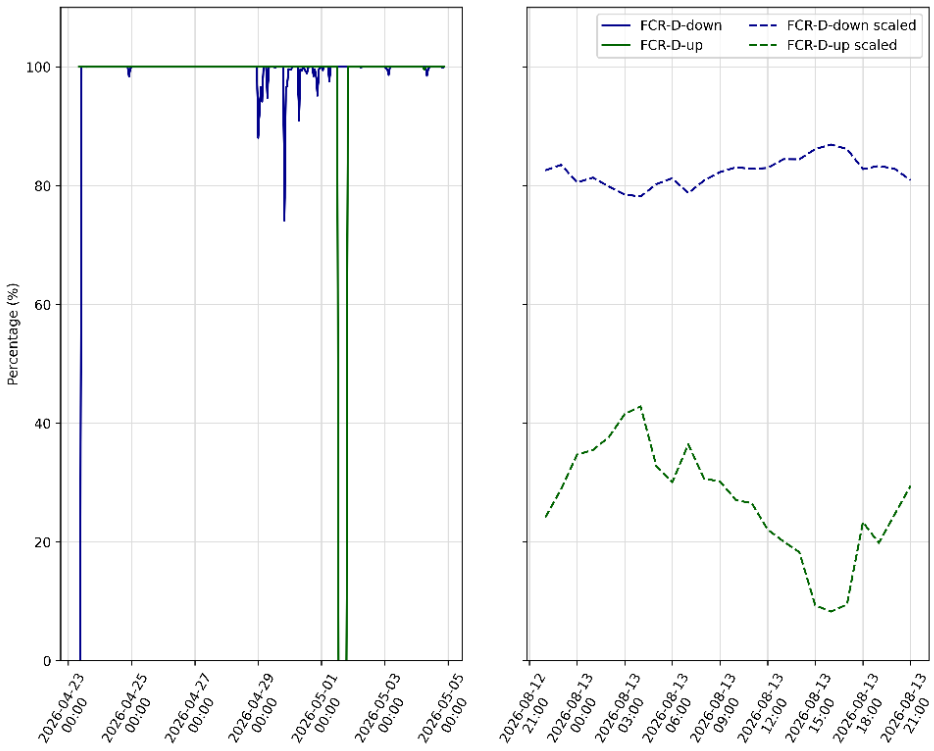


Figure 4: Flexibility utilization

Scaled flexibility logs power utilization observe lower flexibility power utilization for both markets. In FCR-D-down market, average power utilization is 82% with minimum, maximum and standard deviation as 78%, 87% and 2%. FCR-D-up market shows significantly lower flexibility power utilization, an average basis 27% of available power is utilized in maintaining flexibility. Minimum, maximum and standard deviation of 8%, 43% and 9% respectively.

Real-load FCR-D logs shows high flexibility estimation ratio, estimation error and high utilization, implying inadequate forecasting algorithm performance but participating devices are managed highly effectively to match maintained power and available power. Simulated scaled logs shows significant reduction in flexibility estimation ratio and estimation error depicting improvement in forecasting algorithm. However, flexibility utilization reduces, referring to less effective control over maintained devices in case of more available aggregated power in simulated scaled logs.

Combined analysis of flexibility estimation ratio, flexibility estimation error and flexibility utilization improves the assessment. Most favourable scenario includes flexibility estimation ratio and flexibility utilization as 100% and flexibility estimation error as 0%, implying forecasting and offering bid equal to the available power and effectively managing the available power to match maintained power. Higher values of both flexibility estimation accuracy and flexibility utilization signify highly effective forecasting algorithm and effective usage of devices.

Lower flexibility estimation accuracy and high flexibility utilization indicates ineffectiveness in forecasting but effective usage of devices to matching available power and maintained power. Contrary, higher flexibility accuracy and low flexibility utilization implies effective forecasting but ineffective control of devices and utilization not matching the available power.

Table 59: Flexibility utilization summary

KPI		FCR-D-up				FCR-D-down			
		Real logs	Remark	Scaled logs	Remark	Real logs	Remark	Scaled logs	Remark
Flexibility utilization	Mean	97.5 %	Effective power utilization, probable inconsistency in data recording	26.8 %	Ineffective power utilization	98.9 %	Effective power utilization, probable inconsistency in data recording	82.3 %	Effective power utilization
	std	15.7 %		9.3%		8.6%		2.3%	
	Min	99.5 %		8.3%		74.1 %		78.2 %	
	Max	100.0 %		42.8 %		100.0 %		86.9 %	

2.5.3 FI.05 - Bid acceptance rate

Table 60: FI.05 - Bid acceptance rate — KPI definition and assessment

Item	Information
Definition	Proportion of offered power accepted by the TSO to maintain in the FCR-D bid workflow, calculated separately for up and down products.
Unit	%
Scope	FCR-D bid workflow, using real-load flexibility logs and simulated scaled logs with simulated TSO acceptance; associated with FI.01 and FI.05.
STREAM tool(s)	sFLEX, sDATA
Calculation inputs	Offered power from submitted bid samples, service direction, simulated TSO acceptance outcomes and accepted reserved power from bids, sampled hourly.
Comparison / assessment rule	Ratio of total reserved power to total offered power for the same service over the observed duration. Acceptance outcomes are simulated because the live TSO connection was outside the prioritised scope.

Both FCR-D-down and FCR-D-up show a simulated 100% bid success rate. The scenario assumes quick/early submission and competitive prices; therefore, the 100% result demonstrates the assumed bidding scenario rather than observed market success.

$$Bid\ success\ rate = \frac{N_{bids\ accepted}}{N_{bids\ offered}} \times 100$$

Equation 41: Bid success rate

$$Bidacceptancerate = \frac{\sum P_{reserved}}{\sum P_{offered}} \times 100$$

Equation 42: FI.05 calculation

Bid acceptance rate calculation uses both set of logs i.e. real-load pilot observations of limited flexibility participation and simulated scaled logs. Planned bid strategy assumes favourable TSO response for the submitted bid because of quick submission, competitive prices and other relevant consideration involved. Thus, bid acceptance rate is expected to manage over 90% value.

2.5.4 KPIs dismissed

FI.03 (Additional flexibility gained) was originally intended to measure the additional flexibility obtained by allowing room-level temperature variation compared with apartment-level variation. During the KPI revision, this concept was first reconsidered as customised flexibility variations because the user settings were found to reduce the available flexible load rather than create additional flexibility. The related room-level flexibility use case, UC FI.02, was subsequently descoped, and the associated FI-UC.02 test cases were not executed. D5.1 therefore removed FI.03 from the final KPI set.

2.6 CROSS-PILOT TECHNICAL SYNTHESIS AND CONCLUSIONS

The technical impact assessment shows the main results of the STREAM demonstrations in terms of data exchange and communication, forecasting and grid modelling, flexibility identification and availability, registration and prequalification, market participation, flexibility activation and grid-support services. These functions represent different parts of the flexibility-service chain and were demonstrated to different extents in the four pilot sites.

In Slovenia, the demonstrations provide the broadest results of an integrated flexibility chain, covering data exchange, forecasting, grid planning, registration, prequalification and local-market participation. Data collection and communication were highly reliable, generally around 99–100% (SI.01, SI.02), providing a sound basis for the downstream services. Load forecasting showed median relative MAE of about 7–12%, while short-term grid-state forecasts at MV feeder and HV/MV substation level reached WMAPE of 13–19% (SI.04, SI.05). In the controlled local-market demonstrations, all submitted bids were accepted by count and 93.6% of offered flexibility by volume (SI.06), while all 13 registered devices, representing 0.538 MW nominal capacity, passed the demonstrated prequalification procedure (SI.07–SI.12). The complete market workflow from congestion signal to bidding, clearing and activation signal dispatch was therefore successfully demonstrated under the test conditions. The planning simulations also showed that flexibility can avoid a substantial share of reinforcement costs, with GISR of 86.6–100% under reference scenarios, and 39.8–100% under high-stress conditions (SI.03). These results support the technical viability of the Slovenian flexibility chain, but the grid-support effect under naturally occurring congestion was not directly demonstrated because no congestion event occurred during the operational forecasting period.

In Spain, the demonstrations showed that energy-community assets can be registered, prequalified and coordinated through a local flexibility-market workflow, but the amount of flexibility that could actually be delivered remained a limiting factor. Twenty assets were prequalified (ES.08), and 87.5% of eligible automatically generated bids were correctly validated in the demonstration market tests (ES.05). The energy-community operation achieved a 93.6% local self-consumption ratio (ES.06), while the month with community-battery operation showed 30.8% fewer voltage-deviation events than the comparison month without the battery (ES.07). However, only 28.3% of the assessed prequalified capacity was available as flexibility on average (ES.14), 27% of requested flexibility could be covered (ES.11), and average provision compliance was 67.2%, with considerable differences between assets (ES.09). Congestion forecasting, identification and potential resolution were demonstrated only after

deliberately reducing line-capacity thresholds; for example, potential congestion resolution ranged from 70.9% at the 10% threshold to 42.5% at the 20% threshold (ES.04). The Spanish pilot therefore demonstrated the technical operation of the market, prequalification, community-energy and grid-support functions, but the results for routine congestion management remain conditional and the available portfolio was not sufficient to meet most of the requested flexibility.

In Italy, the results demonstrate several technical functions required to identify and prepare flexibility resources for grid and energy-management services. Around 71% of the 41 valid residential meters showed detectable temperature-dependent consumption (IT.03), providing a relevant pool for further HVAC flexibility assessment, although this does not by itself demonstrate dispatchable flexibility. For water pumping, PV-aware scheduling increased locally generated PV energy used for pumping by 35.2% compared with the baseline schedule (IT.04), showing that load scheduling can increase local renewable-energy use. However, this result is based on optimisation of a representative day rather than long-term measured operation. Transformer-loading forecasts achieved monthly WMAPE of 11.19–19.63% (IT.05), while controlled grid-reconstruction validation gave an average error of 2.78%, with a maximum of 13.12% (IT.07). One flexibility provider was also successfully registered and enabled to participate in the marketplace workflow (IT.06). These results support the technical feasibility of forecasting, grid reconstruction, provider onboarding and flexible-load optimization. No real transformer congestion occurred during the assessed period.

In Finland, the demonstrations confirmed that residential electric-heating loads can be aggregated and controlled in response to frequency signals, but the measured performance did not yet consistently meet the FCR-D response requirements. For real-load tests, overall activation compliance was 41% for FCR-D-up and 42% for FCR-D-down against the required 5 s, 7.5/8 s and 30 s response criteria (FI.01). The scaled simulation produced contrasting results, with 0% compliance for FCR-D-up and 100% for FCR-D-down, but these results covered only a limited simulated period. Flexibility estimation also remained challenging: the real-load tests generally overestimated available flexibility, with mean estimation errors of 41.1% for FCR-D-down and 318.8% for FCR-D-up, while the scaled case reduced the average estimation error to 16.3% for FCR-D-down but still showed substantially higher error of 73.2% for FCR-D-up (FI.02). The pilot therefore demonstrated the technical principle of frequency-responsive control and aggregation, but FCR-D service performance was only partially demonstrated under the tested conditions. In addition, bid acceptance was assessed through a simulated TSO interface rather than live market participation (FI.05), so an end-to-end FCR-D service with the TSO was not operationally validated.

Taken together, the results support the technical viability of the STREAM flexibility-service approach under the demonstrated conditions. Individual functions such as data exchange, forecasting, grid modelling, registration and prequalification, automated bidding, asset control, renewable-aware scheduling and flexibility-market processes were successfully demonstrated in different pilots, and Slovenia in particular demonstrated an integrated local-market workflow from grid need to market clearing and activation signalling. Controlled congestion scenarios, planning simulations, limited portfolio availability, variable delivery and control performance, and the absence of a live TSO interface in Finland should be considered when interpreting the overall conclusions STREAM therefore demonstrates that its technical concept and the principal service functions can work, while further operational results would be required to confirm consistent end-to-end flexibility delivery across the different services and operating conditions.

3 ENVIRONMENTAL IMPACT ASSESSMENT

For each pilot site an environmental impact assessment is performed. The assessment follows a system approach, focusing on the impact of flexibility measures supported by the STREAM tools on the (local) grid level, rather than investigating in detail the impact of the software tool development and related controller and IT-hardware components itself, due to their marginal contribution. The environmental impacts of flexibility measures are compared to reference cases involving conventional grid reinforcement measures or the use of other flexibility solutions. In detail the investigated systems are specific for the pilot sites, based on the respective pilot site setup and flexibility measures implemented. Therefore, the obtained results are also linked to the pilot site specifications.

3.1 METHODOLOGY

The method used to evaluate the environmental impacts of the STREAM pilot sites and their flexibility solutions is life cycle assessment (LCA). LCA is a structured, standardized and internationally recognized method for environmental impact assessments.

ISO 14040 and ISO 14044 define the principles, framework, requirements and guidelines for life-cycle assessment, covering environmental impacts across the product life cycle from raw-material acquisition through production, use, end-of-life treatment, recycling and final disposal [4, 5].

The standards structure LCA around four interrelated phases: goal and scope definition, life-cycle inventory analysis, life-cycle impact assessment and interpretation [4, 5].

(1) goal and scope definition,
(2) inventory analysis,
(3) impact assessment, and
(4) interpretation.

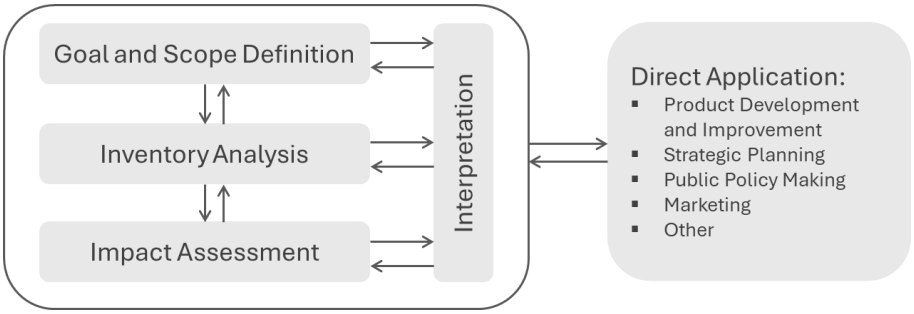


Figure 5: Life cycle assessment framework according to ISO14040

For each pilot site, goal and scope of the assessment are described in the following sections. The most important foreground data (pilot-site-specific data) and background data (data of up- and downstream processes in the value chains from LCA databases and literature sources of the inventory are presented, and the results of the impact assessment are described and conclusions are drawn.

3.1.1 Investigated Environmental Impacts

The investigated environmental impacts are global warming potential (GWP) and cumulative energy demand (CED).

The Global Warming Potential on a 100 years' time horizon according to IPCC 2021 was used to express the contribution of greenhouse gases (e.g. CH_4, N_2O, R-14) to global warming, in terms of equivalent amount of CO_2 (CO_2e) [6]. CO_2 emissions from burning biomass are balanced zero according to IPCC guidelines [7].

The CED includes all primary energy required throughout the life cycle of a product, material or service. The CED indicator used in this study is based on the lower heating value of the energy carriers (Cumulative Energy Demand (LHV)) and is divided into the following categories:

- non-renewable (e.g. crude oil, coal, lignite, natural gas, nuclear, municipal waste) (CEDnr); and
- renewable (e.g. solar, wind, water, biomass) (CEDr).

The sum of CEDnr and CEDr represents the total CED (CEDtot).

3.1.2 Data Sources

Two different types of data categories are used in LCAs: (1) foreground and (2) background data. Foreground data are pilot-site-specific data, that have a significant influence on the total environmental impacts of the investigated systems (e.g. amount and type of materials used for infrastructure installation, types of electricity generators, and electricity flows). These data were collected within the project or calculated using the STREAM Tools (sPLAN or sGRID). The foreground data are combined with background data, which link the foreground to up- and downstream processes and related environmental impacts (e.g. production of primary aluminium, electricity generation in a natural gas power plant). Background data are obtained from the life cycle database ecoinvent 3.12. (Cutoff-dataset) [8], GEMIS 5.1 [9] and the cited literature. GWP data and CED data directly obtained from the ecoinvent database cannot be published here due to licensing reasons. In Annex A, a list is included with the process names used per pilot site.

3.2 SLOVENIAN PILOT SITE

3.2.1 Goal and Scope

The goal of the LCA in the Slovenian use case is to compare the environmental impacts of local grid upgrade scenarios with and without flexibility options. In detail the goal is to show the shares of environmental impacts related to infrastructure and to electricity generation as well as to compare the relative difference of environmental impacts of hardware installation only with and without flexibility in the scenarios.

The comparison is based on scenarios calculated in sPLAN simulations. Each scenario is defined by combing 1 out of 6 technical settings:

- Baseline,
- PV: additional PV,
- PV+BESS: additional PV with battery energy storage,
- EV+HP: electrification with electric vehicles and heat pumps,
- EV+HP+PV: electrification with EV and HP plus PV,
- Combined: electrification with EV and HP in combination with PV and BESS.

1 out of 3 grid stress levels (low stress, reference, high stress) and 1 out of 4 seasons (spring, summer, autumn, winter), which results in 72 scenario pairs, each with and without flexibility options.

The 72 scenario pairs are compared based on the so-called functional unit (describing the function of the local grid) of 1 kWh electricity supplied to non-flexible and flexible consumers and to the transmission grid in case excess PV electricity is available in the local grid.

3.2.2 Data

3.2.2.1 Foreground data

The simulations with the STREAM tool sPLAN provide net consumption of electricity, flows from and to the transmission grid, photovoltaic production, use of battery storage, and grid losses. The

combination of technical setting and grid stress level applied to one week each in spring, summer, autumn and winter delivers foreground data for life-cycle inventories of all scenarios in a 15-minute resolution.

In Figure 6 the processing of foreground data (electricity flows of one week) is demonstrated for one scenario. It shows the “Combined scenario” on a high grid stress level, combining electric vehicles and heat pumps as flexible consumers, with photovoltaic electricity production and battery storage available in the local grid. The electricity mix imported from the transmission grid corresponds to a typical week in summer. In times of excess PV electricity available in the local grid, it is exported to the transmission grid, displayed in Figure 6 as negative values. The week starts with a Sunday.

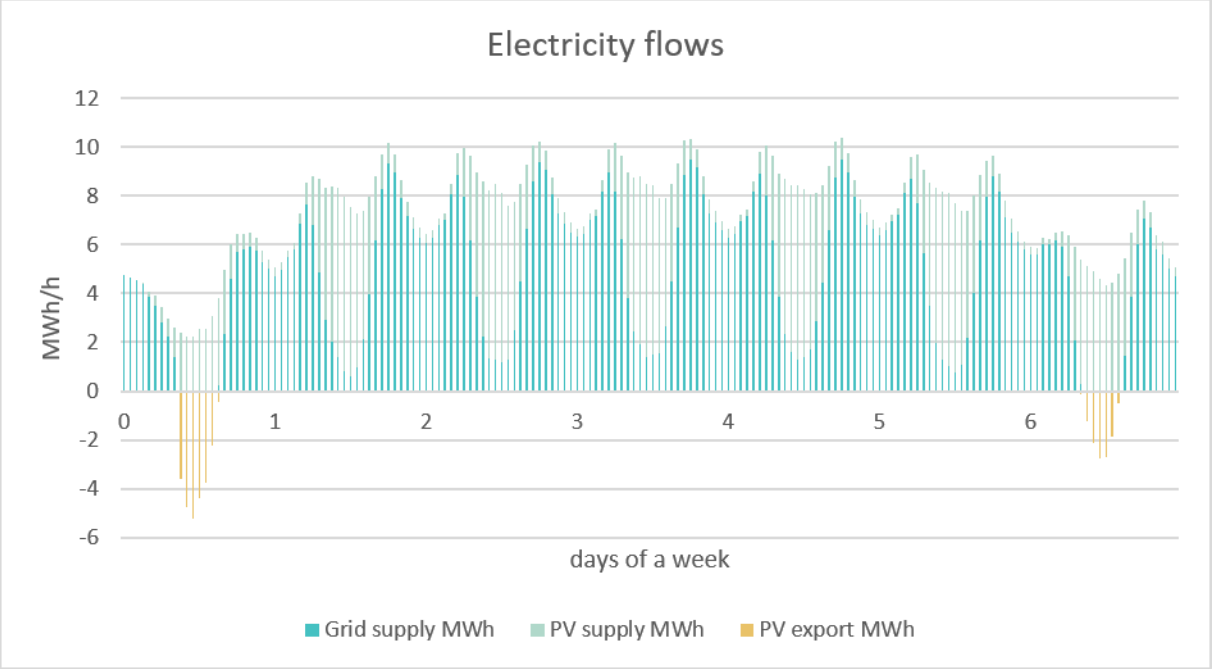


Figure 6: Combined scenario (electrification, PV and storage) on a high stress level. Average electricity flows per hour over one week in summer.

The electricity mix in the transmission grid is then multiplied with background impact data to assess the environmental impacts for each time step (hourly). The origin of the applied factors for each power plant is described in section 3.2.2.2. Whenever excess PV electricity in the local grid is exported to the transmission grid (see Figure 6), it is assumed that in the transmission grid electricity from natural gas power plants (as the most expensive flexible electricity source in the merit order) is replaced, and respective emission factors EF ($EF_{el\ from\ NG} - EF_{elfrom\ PV}$) are assigned to these negative electricity flows, resulting in negative emissions. The sequence of global warming potential and cumulative energy demand is presented in Figure 7 and Figure 8, respectively.

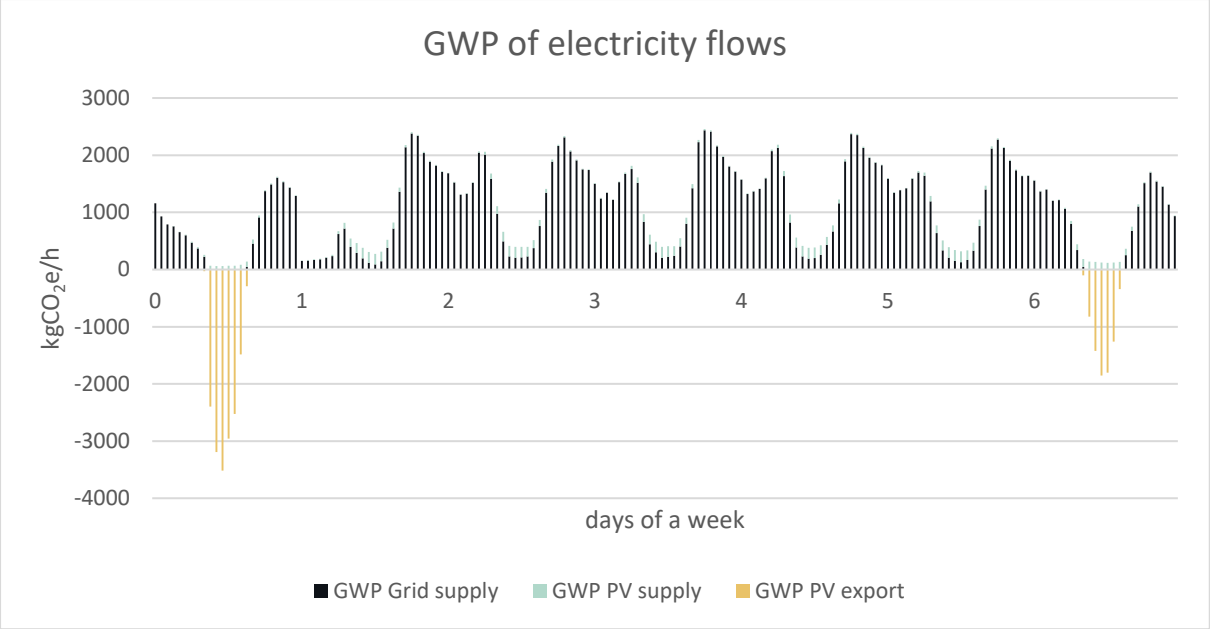


Figure 7: Combined scenario (electrification, PV and storage) on a high stress level. Average GWP per hour over one week in summer.

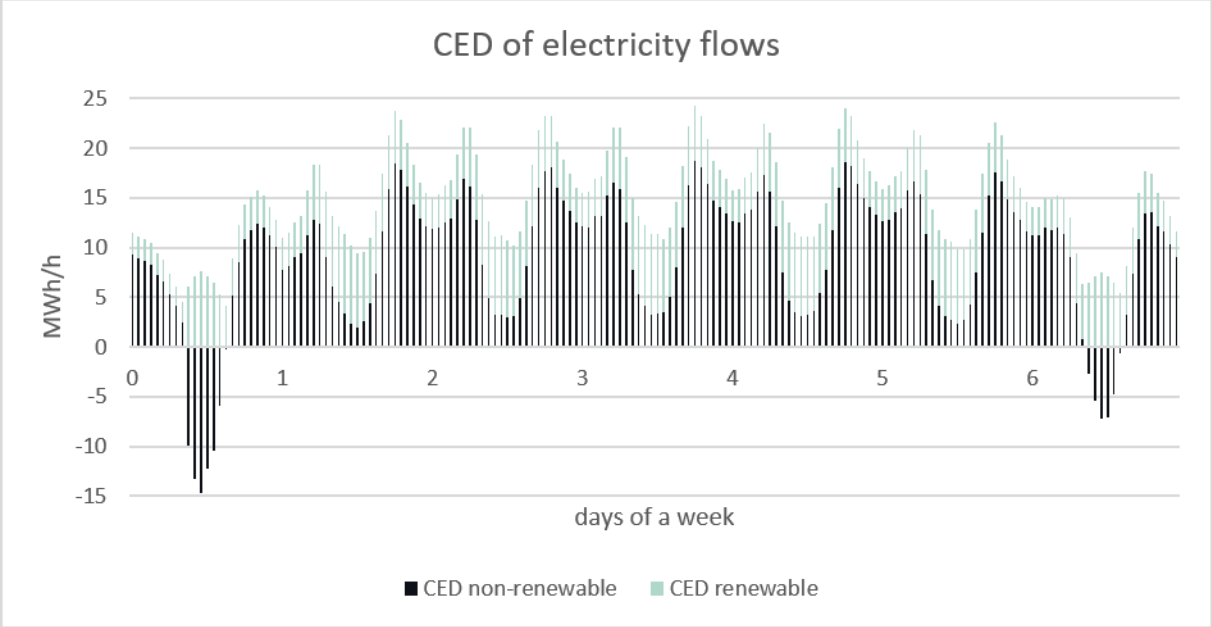


Figure 8: Combined scenario (electrification, PV and storage) on a high stress level. Average renewable and non-renewable CED per hour over one week in summer.

The sPLAN simulations deliver data also about additional components for grid upgrade and flexibility, such as transformers and a variety of cables. Life cycle inventories have been calculated based on the main materials used in these hardware components such as aluminium, copper, steel, XLPE, PVC and transformer oil. Additionally, data for sand, gravel and excavation of underground cable routes have been considered.

3.2.2.2 Background data:

The ENTSOE Transparency platform [10] delivered electricity mix data for each day of a week by analysing the generation per production type for the first weeks in March, June, September and December in 2024 in Slovenia (Figure 9).

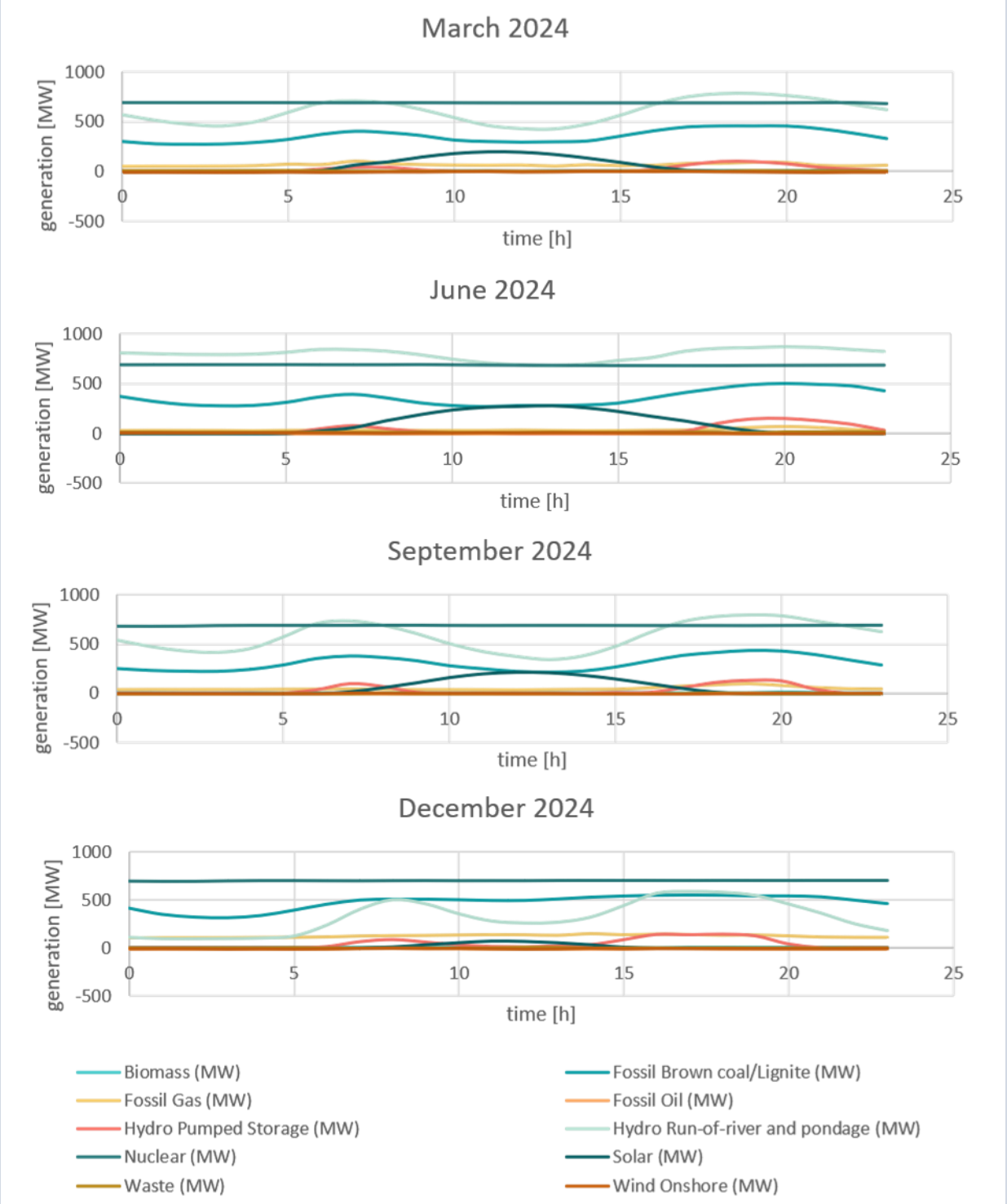


Figure 9: Average electricity mix in the Slovenian grid according to ENTSOE in the four considered months.

For assessing the environmental impacts of each electricity production technology in Slovenia, life-cycle data have been taken from the ecoinvent 3.12 Cutoff database [8]. The database delivered

satisfying data quality for the GWP and the CED of electricity production from biomass, fossil gas, lignite, oil, hydro (run-of-river and pondage as well as pump storage), wind (onshore) and nuclear energy. Values for photovoltaic have been derived from [11] and adjusted to local annual irradiation/production for Ajdovščina using the European Commission PVGIS tool [12], as shown in Table 61. The environmental impacts of electricity from waste combustion and impacts of the battery storage are derived from expert estimations of appropriate reference projects.

Table 61: GWP and CED for electricity production from PV in Ajdovščina. Calculated by JOANNEUM RESEARCH based on [11] and [12]

	GWP [g CO2e/kWh]	CEDtot [kWh/kWh]	CEDnr [kWh/kWh]	CEDr [kWh/kWh]
PV electricity	26.8	1.13	0.11	1.02

Figure 10 shows the environmental impacts of the Slovenian electricity mix per kilowatt hour exemplary for one week in June. The GWP is reduced in times of low electricity consumption due to higher shares of renewable sources.

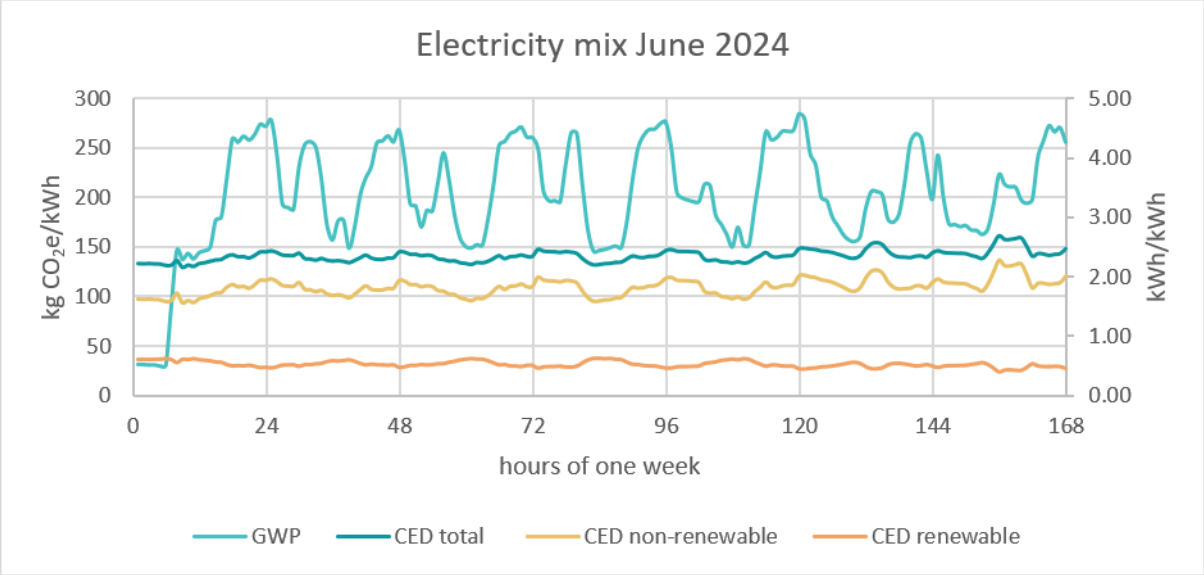


Figure 10: GWP and CED of one week in June 2024 according to the average electricity mix in the Slovenian grid in ENTSOE. The week starts with a Monday.

For grid upgrade and the provision of additional flexibility options, data for cables and transformers such as length of cables and certain technical specifications were provided as well as results of sPLAN simulations of each scenario. The ecoinvent database delivered GWP and CEDtot, CEDnr and CEDr of the main materials used in these hardware components such as aluminium, copper, steel, XLPE, PVC and transformer oil. Additionally, data for sand, gravel and excavation of underground cable routes have been considered.

3.2.3 Environmental Impact Results

3.2.3.1 Impacts of electricity consumption

In a first step, the total impacts of each scenario including grid upgrade or flexibility option have been calculated as global warming potential and as cumulative energy demand. Table 62 provides as an example an overview of all scenarios in a summer week. The consumed energy is the sum of the grid balance (from and to grid) and produced PV electricity. The GWP and CED have been calculated for the respective amount of electricity.

Table 62: Overview of the total energy consumption of all technical settings and stress levels in summer and their respective environmental impacts.

1 Week Summer			Low stress	Reference	High stress
PV	Electricity from Grid	[MWh]	920	866	724
	Electricity from PV	[MWh]	130	217	396
	PV-electricity to Grid	[MWh]	-3	-11	-51
	Electricity tot	[MWh]	1047	1072	1069
	GWP tot	[t CO2e]	193	181	135
	CED tot	[MWh]	2318	2280	2090
PVBESS	Electricity from Grid	[MWh]	922	868	724
	Electricity from PV	[MWh]	128	214	395
	PV-electricity to Grid	[MWh]	-2	-9	-42
	Electricity tot	[MWh]	1048	1073	1077
	GWP tot	[t CO2e]	193	182	139
	CED tot	[MWh]	2318	2292	2117
EV+HP	Electricity from Grid	[MWh]	1060	1126	1226
	Electricity from PV	[MWh]	0	0	0
	PV-electricity to Grid	[MWh]	0	0	0
	Electricity tot	[MWh]	1060	1126	1226
	GWP tot	[t CO2e]	217	231	252
	CED tot	[MWh]	2499	2656	2893
EV+HP+PV	Electricity from Grid	[MWh]	934	914	832
	Electricity from PV	[MWh]	130	218	404
	PV-electricity to Grid	[MWh]	-2	-10	-43
	Electricity tot	[MWh]	1061	1122	1192
	GWP tot	[t CO2e]	196	192	164
	CED tot	[MWh]	2356	2406	2385
Combined	Electricity from Grid	[MWh]	935	916	834

Electricity from PV	[MWh]	128	215	401
PV-electricity to Grid	[MWh]	-2	-8	-36
Electricity tot	[MWh]	1062	1123	1199
GWP tot	[t CO2e]	196	193	167
CED tot	[MWh]	2358	2409	2395

The scenarios comprise three dimensions: technical setting, grid stress level and the season. The amount of consumed energy is modified by these technical settings, the different stress situation, and the seasonal circumstances. For a quantitative comparison between the scenarios from an environmental perspective, values have been normalised to one kilowatt hour of consumed electricity. The GWP is presented graphically for summer and winter in Figure 11. The CED behaves similar to these values.

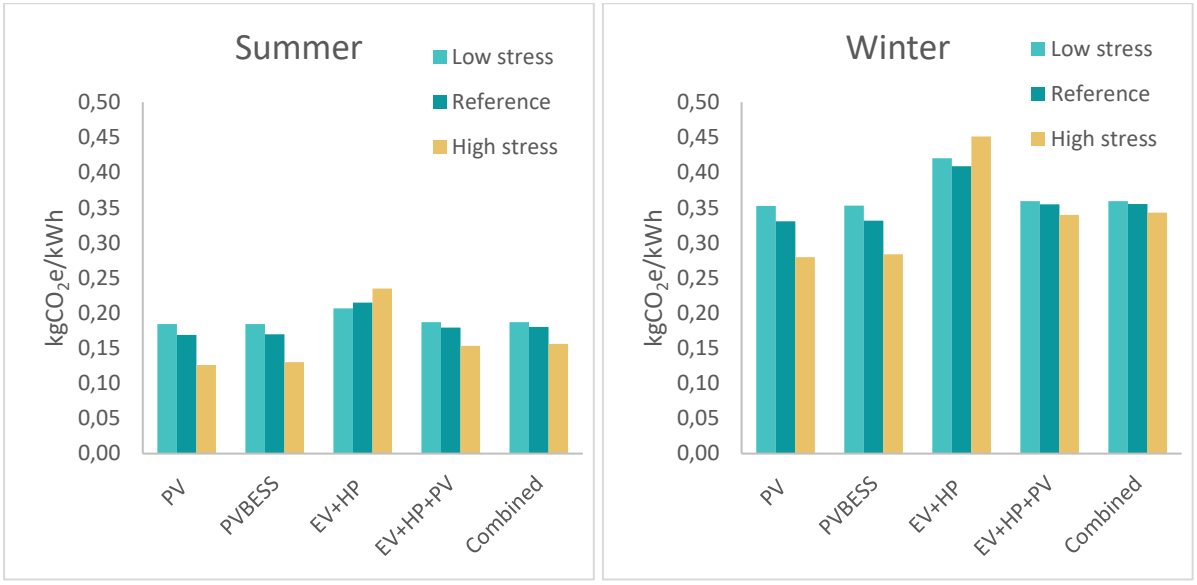


Figure 11: GWP per 1 kWh electricity consumption for all scenarios in summer and winter.

The following main results can be summarized:

- In the high stress scenarios “PV”, “PVBESS”, “EV+HP+PV” and “Combined” the GWP (and CED_{tot}) per kWh is lower compared to low stress and reference scenarios with certain shares of PV-electricity produced and consumed in the local grid. This is due to the low GWP and the CED of electricity from photovoltaics compared to fossil energy carriers. Only in the “EV+HP” scenario, the high stress scenario results in higher GWP and CED since all electricity consumed is supplied by the electricity mix from the transmission grid with a higher share of fossil energy carriers.
- While the absolute impacts are strongly depending on the season, most of the relative effects between the technical settings and stress levels behave proportionally.

3.2.3.2 Impacts of grid upgrade and flexibility measures

For all scenarios, grid upgrade and flexibility measures have been simulated, they are included in the impact assessment as additional impacts. Their impact assessment is based on an inventory of materials of cables and transformers, also covering excavation activities. The considered

infrastructure is assumed to have a lifetime of 30 years. It causes an additional impact, which is very low for all scenarios compared with the impacts from electricity in total. Table 63 shows these impacts as absolute values, but also relatively normalised on the case where grid is upgraded without flexibility. This demonstrates the saved impacts h due to flexibility, which are calculated as follows:

$$\overline{h}_{saved} = 1 - \frac{h_{grid+flex}}{h_{grid}}$$

Equation 43: Normalised impacts h

Table 63 shows details of the impacts exemplary for the Combined scenario on a high stress level. Values are aggregated over one week in summer. Electricity flows from and to the grid and from PV are presented separately. Their impacts are split up in GWP, CEDtot, CEDnr and CEDr.

Table 63: Combined scenario (electrification, PV and storage) on a high stress level. Values aggregated over one week in summer for electricity flows, GWP and CED. Additional impacts from grid upgrade and grid upgrade with flexibility measures, and relative reduction of impacts of grid upgrade when flexibility options are used (Saved by Flex).

1 Week Summer	Electricity	GWP	CEDtot	CEDnr	CEDr
	[MWh]	[t CO2e]	[MWh]	[MWh]	[MWh]
El from Grid	833.53	180.05	1990.41	1576.85	413.56
El from PV	401.07	10.80	469.52	59.67	409.85
El to Grid	-35.82	-24.01	-66.43	-102.60	36.16
El total supply	1199	167	2395	1536	860
Grid upgrade	-	0.51	1.99	1.94	0.05
Grid upgrade + flexibility	-	0.28	1.07	1.05	0.02
Saved by Flex	-	46%	46%	46%	49%

Table 64 shows the most relevant impacts for all scenarios in Summer. It demonstrates the deviations in total electricity supply and also scenario dependency in the impacts. The absolute impacts of grid upgrade and flexibility are small. Nevertheless, they depend strongly on the scenario and significant relative differences occur. The saved impacts due to flexibility are calculated as greenhouse gas emissions reduction when, additionally to grid upgrade, flexibility options are applied. The results range from almost 0% in the pure photovoltaic scenarios under a low stress level to 63% for electrification without photovoltaics at a high stress level.

Table 64: Aggregated electricity flows and GWP over one week in summer for all technical settings and stress levels. Additional impacts from grid upgrade and grid upgrade with flexibility measures and relative reduction of impacts of grid upgrade when flexibility options are used (Saved by Flex).

	1 Week Summer		PV	PVBESS	EV+HP	EV+HP+PV	Combined
Low stress	El total supply	[MWh]	1050.03	1049.74	1060.12	1063.86	1063.57
		[t CO2e]	194.49	194.00	216.41	197.48	196.99
	Grid upgrade	[t CO2e]	0.26	0.26	0.28	0.26	0.28
	Grid upgrade + Flexibility	[t CO2e]	0.26	0.26	0.24	0.23	0.23
	Saved by Flex	-	0%	0%	14%	12%	17%
Reference	El total supply	[MWh]	1082.72	1082.17	1126.04	1131.78	1131.19
		[t CO2e]	188.08	187.50	230.19	198.52	197.98
	Grid upgrade	[t CO2e]	0.28	0.30	0.31	0.30	0.30
	Grid upgrade + flexibility	[t CO2e]	0.28	0.30	0.26	0.25	0.25
	Saved by Flex	-	0%	0%	17%	16%	16%
High stress	El total supply	[MWh]	1120.33	1119.20	1225.84	1235.86	1234.61
		[t CO2e]	168.86	166.98	251.08	192.58	190.85
	Grid upgrade	[t CO2e]	0.52	0.54	0.66	0.59	0.51
	Grid upgrade + flexibility	[t CO2e]	0.28	0.28	0.25	0.28	0.28
	Saved by Flex	-	47%	49%	63%	53%	46%

The saved GWP by flexibility options is shown for all seasons as relative values in Figure 12. Values for CED are very similar. Compared to the values for summer (Table 64), results for spring and autumn do not deviate much. In Winter, however, the strong dependency on the stress level does not apply for the electrification scenarios. The scenarios without electrification deliver at high stress level only a slight decrease of GWP.

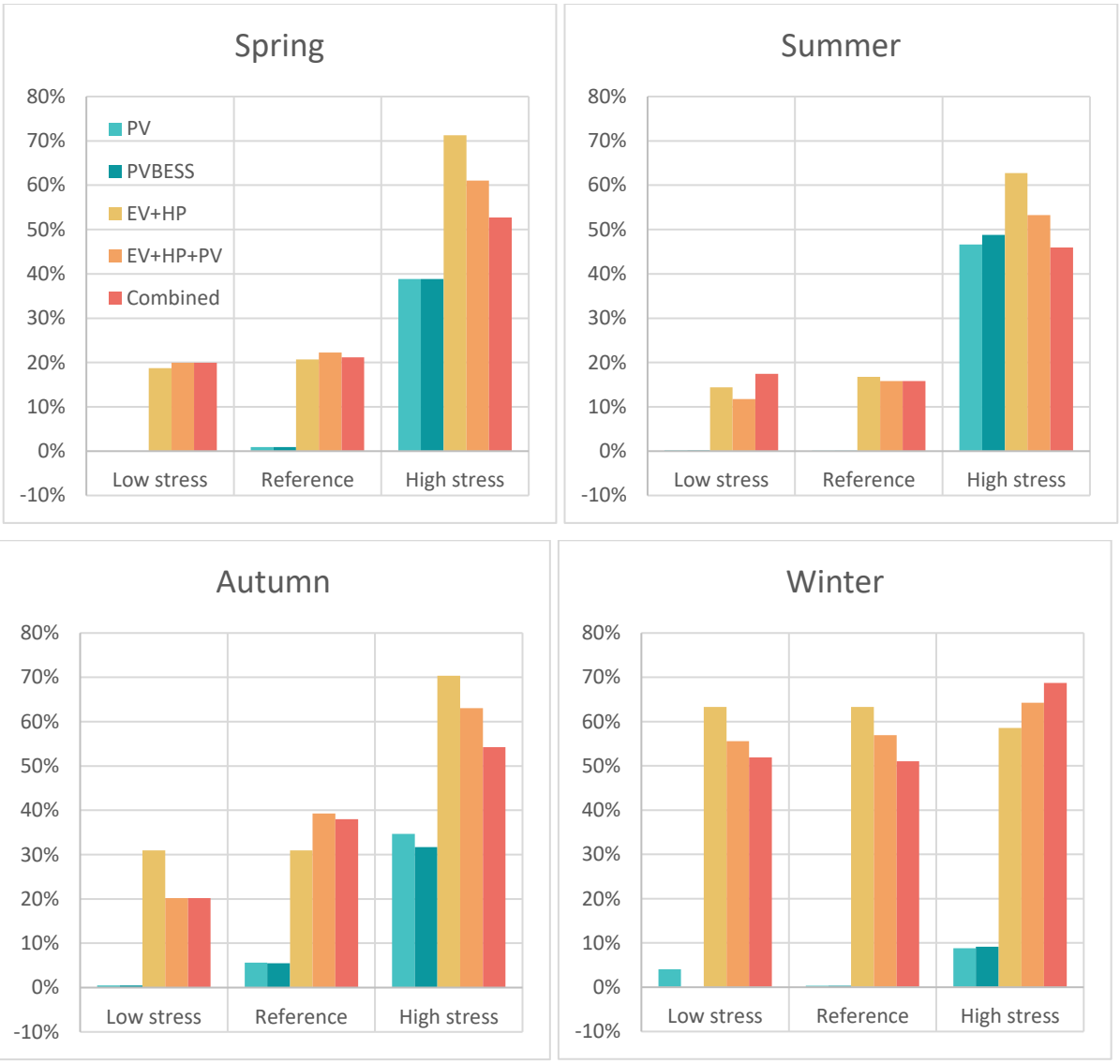


Figure 12: Reduction of GWP from grid upgrade with flexibility options as relative value normalised to grid upgrade without flexibility option for all technical settings, stress levels, and seasons. PV: photovoltaics, PVBESS: photovoltaics with battery storage, EV+HP: electrification (electric vehicles and heat pumps), EV+HP+PV electrification with photovoltaics, Combined: electrification with photovoltaics and battery storage.

3.2.4 Conclusions

The environmental assessment demonstrates that grid upgrade and flexibility options have a very small impact compared to the total impact of electricity production in the grid. Electricity production causes a GWP between 158 and 447 kg CO_2e per week, while the emissions for grid upgrade are between 0.21 and 0.92 kg CO_2e and for grid update with flexibility between 0.14 and 0.39 kg CO_2e per week. In most cases, the impacts are smaller than deviations in impacts of electricity production between the differently assumed scenarios.

Flexibility has the potential to reduce impacts of grid update, as energy demand and greenhouse gas emissions for building new infrastructure can be avoided. The largest effects are expected for high stress levels and for systems including electric vehicles and heat pumps.

In conclusion, the life-cycle assessment demonstrates the ecological benefits of the flexibility options as part of the grid in the context of electricity consumption. Since the grid in general is a very small contributor to the environmental impacts of electricity consumption, grid improvements do not contribute much. Nevertheless, from a grid perspective, a significant improvement can be observed.

3.3 SPANISH PILOT SITE

The main industrial asset providing flexibility in the Spanish pilot site is the installation of the community PV installation (120kWp) + the battery storage (240kWh), connected to El Salá transformer centre. Currently, the battery is crucial in integrating the locally generated PV power since it's injecting reactive power (Q) into the grid to stabilize the voltage. Without it, the grid experiences voltage deviations that would require curtailment of PV generation.

In addition to this installation, Crevillent's energy community includes:

- Municipal PV installations: 465 kWp in total (schools, sports centres, museums).
- EV charging network: nearly 400 kW.
- Prosumers' assets: 48 kWp of PV panels and 90 kWh of battery capacity.

3.3.1 Goal and Scope

The assets of the energy community are distributed across different sections of the grid. However, the section in which the community PV and battery installation is located is the most relevant for flexibility provision and, consequently, for achieving a significant environmental impact. Therefore, the LCA focuses exclusively on the community PV system in combination with the battery.

The goal of the LCA is to analyse the GWP and CED of the battery used to stabilize the grid voltage, thereby enabling the integration of local PV generation. To assess the impact of the battery the following 4 cases are investigated:

1. "Case 1: battery": This case represents the situation at the pilot site including PV generation and the battery as flexibility asset.
2. "Case 2: w/o battery and no PV": This case is without the battery. PV is curtailed completely. This case represents a situation at the pilot site, in spring 2026, when the battery was out of order. At this time the PV production was shut down completely.
3. "Case 3: w/o battery with PV partly used": Here it is assumed that a certain share of PV can be used in the grid section, even if no battery is installed. The amount of PV was calculated based on monitoring data from the pilot site as delta between PV production and battery charging.
4. "Case 4: grid reinforcement": This case investigates the option to reinforce the grid instead of using a battery. If local PV generation exceeds local consumption PV electricity is exported to another grid section.

The functional unit of the comparison is the electricity consumption in the investigated grid section of one year. It was calculated based on monitoring data from the year 2025 and set to be the same in all investigated cases.

3.3.2 Data

3.3.2.1 Foreground data

In a first step monitoring data from the Spanish pilot site on different electricity flows (PV production, energy import/export, battery charging/discharging) was analysed for two situations at the pilot site:

(1) operation with battery from 7.5.2024 – 26.3.2026; 1.6.2026 – 21.7.2026, and
(2) operation without battery from 27.3.2026 – 31.05.2026.

In detail the time interval 7.5. – 31.5. was analysed for the years 2024 (with battery), 2025 (with battery), 2026 (without battery) to see the difference between the operation with and without the battery. Based on this analysis the following framework for the LCA was defined:

- The amount of electricity exported from the El Salá grid section is very small (less than 1% of the imported electricity). Also, the comparison of the periods with battery and without battery showed no differences for the exported electricity (Figure 13). Therefore, the monitoring data for the exported electricity is neglected in the LCA.
- PV production is in the same range in the years 2024 and 2025. In 2026 PV production went down almost to zero, when the battery did not operate (Figure 14). The impact of curtailing the PV completely is investigated in "Case 2: w/o battery and no PV".
- The monitoring data for the year 2025 is used as the data basis in the LCA as for 2025 hourly data for a full year is available. This data reflects the situation with battery operation and was used for "Case 1: battery".

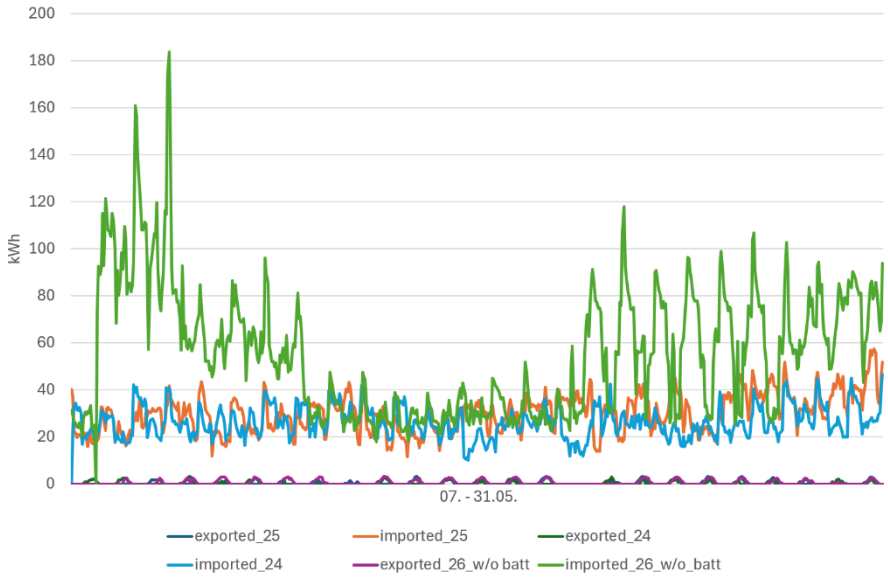


Figure 13: Electricity import and electricity export in the El Salá grid section of the pilot site from 7.5. – 31.5. in the years 2024 (with battery), 2025 (with battery) and 2026 (without battery).

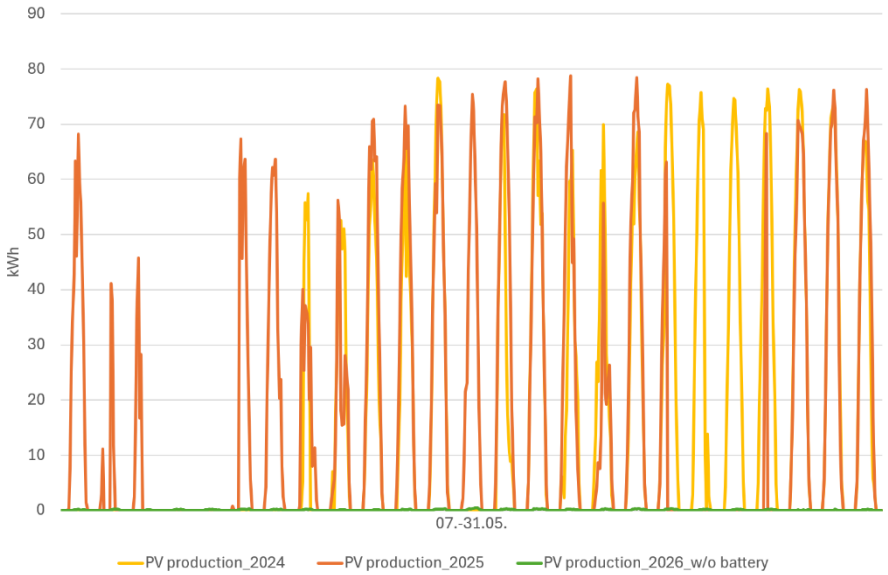


Figure 14: PV production in the El Salá grid section of the pilot site from 7.5. – 31.5. in 2024 (with battery), 2025 (with battery) and 2026 (without battery)

All cases compared to each other in an LCA must fulfil the same service (functional unit), which is here covering the electricity consumption of the El Salá grid section in the year 2025. The electricity consumption was calculated based on the electricity balance of the grid section as follows:

$$E_{Con} = \left(E_{Imp} + PV_{Pro} + Bat_{Dis} - Bat_{Cha}\right) \times 0.963$$

Equation 44: Spanish pilot electricity balance

with

E_{Con}	Electricity consumption in the El Salá grid section
E_{Imp}	Electricity imported to the El Salá grid section
PV_{Prod}	Electricity generated with PV in the El Salá grid section
Bat_{Dis}	Electricity discharged from the battery
Bat_{Cha}	Electricity charged to the battery
0.963	Factor for losses in the distribution grid

For the imported electricity the electricity production mix in Spain was assumed. To calculate the GWP and CED for Spanish production mix data for 2025 from the ENTSOE Transparency platform [10] was used. For the period from 28.04.2025 12:00 to 30.04.2025 00:00 no production data was available. Therefore, this period was removed from the monitoring dataset, accepting that the yearly data misses 36 hours.

Based on these assumptions an electricity consumption in the El Salá grid section for 2025 of 453 MWh was determined.

In a next step the electricity flows for the Cases 2 to 4 were calculated in an hourly resolution keeping the electricity consumption the same in all cases. Table 65 shows the results.

In Case 1 und Case 4 full PV production is allowed, leading to lower electricity imports. In Case 4, with grid reinforcement measures (additional cable + transformer), a small amount of electricity is exported from the El Sala grid section. Export takes place if PV production exceeds consumption.

Table 65: Yearly PV production (PV_{Prod}), imported (E_{Imp}), exported (E_{Exp}) and consumed electricity (E_{Con}) of the LCA cases

	PVProd	EImp	EExp	ECon
	[MWh/a]			
Case 1: battery	128	347	-	453
Case 2: w/o battery and no PV	0	471	-	453
Case 3: w/o battery with PV partly used*	78	393	-	453
Case 4: grid reinforcement	128	353	10	453

**amount of PV was determined by delta between PV production and battery charging*

Besides the electricity flows additional hardware was included in the assessment:

Case 1: battery:

- 240 kWh, 100 kW Lithium Iron Phosphate Battery
- Inverter BESS, 100 kVA

Case 4: grid reinforcement:

- 600 m cable, aluminium, 1×240 mm²
- 630 kVA transformer
- 600 m trenching for underground cable

3.3.2.2 Background data

For assessing the environmental impacts of each electricity production technology in Spain, life-cycle data has been taken from the ecoinvent 3.12 Cutoff database [8]. The database delivered satisfying data quality for GWP and the CED (total, non-renewable, renewable) for electricity production for biomass, fossil gas, fossil hard coal, fossil oil, pumped storage, hydro run-of-river and pondage, hydro water reservoir, nuclear, waste and wind. Values for PV have been derived from [11]. To consider local solar irradiation, they have been modified to the yearly energy production per kWp in Crevillent according to the photovoltaic geographical information system from the European Commission [12]. The obtained factors are shown in Table 66.

Table 66: GWP and CEDtot, CEDnr, CEDr for electricity production from PV in Crevillent, Spain. Calculated by JOANNEUM RESEARCH based on [11] and [12]

	GWP [g CO2e/kWh]	CEDtot [kWh/kWh]	CEDnr [kWh/kWh]	CEDr [kWh/kWh]
PV electricity	21	1.10	0.08	1.01

3.3.3 Environmental Impact Results

The results of the LCA on GWP and CED for investigated cases for the Spanish pilot site are presented in the following figure and Table 67.

Figure 15 shows the results on GWP divided into the shares "operation (including grid electricity, locally generated PV electricity, battery charging/discharging losses, transmission losses)" and "battery production/grid reinforcement (including the production of battery and inverter and for the grid reinforcement measure cable, transformer, trenching)". However, the impact of the "battery production/grid reinforcement" on the total GWP for electricity provision is very low (1-2%). The result is dominated by the GWP linked to the electricity generation, mainly to grid electricity generation and to a very small account to the locally generated PV electricity (2-4% in the cases with PV electricity). "Case1: battery", which represents the setup of the pilot site has the second lowest GWP with 66 t $CO2_e$ per year. "Case 4: grid reinforcement" has the lowest GHG emissions. In both PV electricity production is the same. However, charging and discharging of the battery has higher losses (round trip battery efficiency of approx. 90% based on monitoring data from 2025) than the low voltage network (96%) leading to a higher need of grid electricity in Case 1. Case 2 the electricity demand is covered 100% from grid electricity leading to a GWP of 81 t CO_2e. In Case 3 it is assumed that 61% of the locally produced PV electricity can be used directly resulting in 72 t CO_2e per year.

Figure 16 shows the results on CED. The ranking between the cases is the same as for the GWP. In all cases the share of renewable energy is relatively high (70 to 77%). This is linked to (1) the higher share of renewable energy in the Spanish electricity generation mix (69%) and the locally used PV electricity.

Table 67: shows the GWP and CED per kWh of electricity consumed for the four investigated cases. Case 1 and Case 4 have the lowest GWP values, at 146 and 139 g CO_2e/kWh, respectively. The absence of local PV electricity in Case 2 results in a higher GWP of 180 g CO_2e/kWh. With a GWP of 159 g CO_2e/kWh, Case 3 lies between the other cases. Again, the high share of renewable energy in the CED is evident.

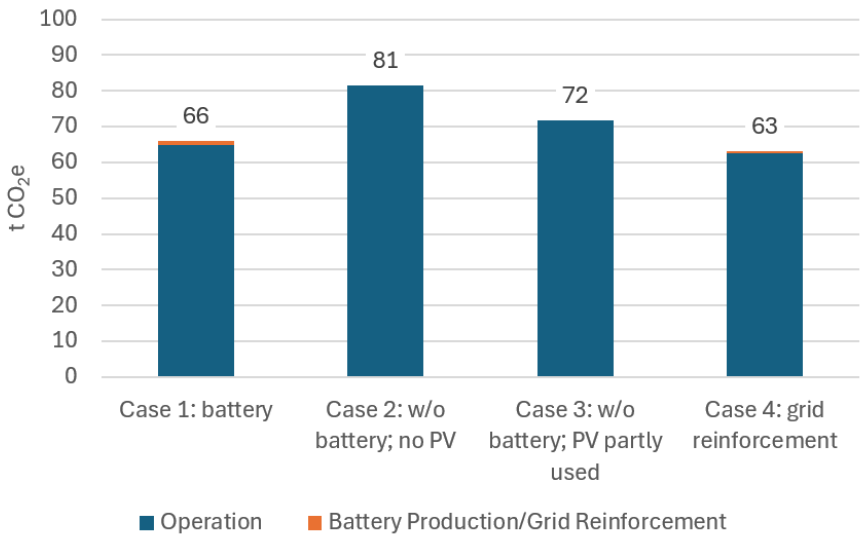


Figure 15: LCA result on GWP of the four investigated cases of the Spanish pilot site

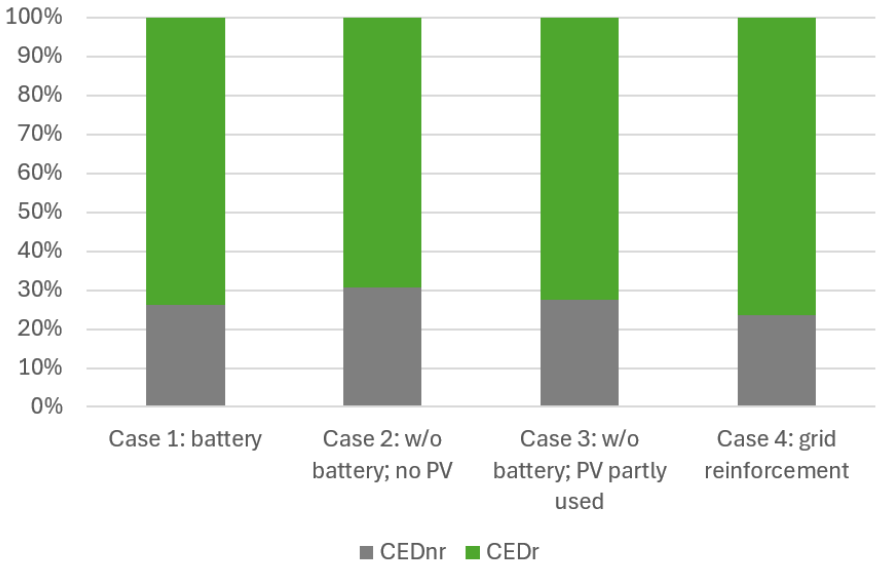


Figure 16: Result on the shares of CEDnr – non-renewable and CEDr – renewable of the four investigated cases of the Spanish pilot site

Table 67: GWP and CED per kWh electricity consumed in the investigated grid section

	GWP	CEDtot	CEDnr	CEDr
	[g CO2e/kWh]	[kWh/kWh]	[kWh/kWh]	[kWh/kWh]
Case 1: battery	146	1.89	0.49	1.40
Case 2: w/o battery and no PV	180	2.10	0.64	1.46
Case 3: w/o battery with PV partly used	159	1.95	0.54	1.42
Case 4: grid reinforcement	139	1.86	0.44	1.43

3.3.4 Conclusions

Based on the LCA results on GWP and CED the following conclusions are drawn:

The environmental impact is mainly determined by electricity generation rather than infrastructure. The contribution of battery production and grid reinforcement to total GWP is only 1–2%, while the impacts associated with electricity provision dominate the results.

Grid reinforcement results in the lowest environmental impact among the investigated cases. Case 4 has the lowest GWP at 139 g CO_2e/kWh, compared with 146 g CO_2e/kWh for the battery-based Case 1. This difference is mainly attributed to the higher losses associated with battery charging and discharging compared with the low-voltage network.

Case 2, which relies entirely on grid electricity, has the highest GWP at 180 g CO_2e/kWh, whereas the partial direct use of PV electricity in Case 3 reduces the GWP to 159 g CO_2e/kWh. Across all cases, the renewable share of the CED remains high at 70–77%, mainly due to the high renewable share of the Spanish electricity mix and the locally used PV electricity.

3.4 ITALIAN PILOT SITE

The main objective of the Italian pilot site is to explore how flexibility from different types of assets can support the operation of the electricity distribution network of the city of Terni. In particular, the pilot investigates the potential of coordinating flexible loads and distributed resources connected to the grid. This includes the assessment of flexibility from the water distribution system and electric vehicle charging infrastructure. For the environmental impact assessment, the focus was set on the flexibility of the water distribution system as for water pump operation in the water pumping station of Terni an optimization case was investigated with the optimization of the use of locally produced PV electricity. In addition to the water pumping case, a second case was assessed for the flexible charging of electric vehicles, based on the charging infrastructure operated by EMOT at the pilot site. This case is assessed on modelled charging profiles.

3.4.1 Goal and Scope

The goal of the LCA for the Italian pilot site is to investigate the change of GWP and CED for three different optimization cases of the water pumps of the water pumping station in Terni compared to the water pump baseline operation. The three following optimization cases are investigated:

1. Cost optimized: Minimisation of electricity cost based on day-ahead market prices
2. PV optimized: Maximisation of local renewable self-consumption
3. Congestion optimized: Mitigation of forecasted transformer congestion

Detailed information on these optimization cases can be found in Deliverable 5.1, ANNEX B – 8.3 Italian Pilot Site, IT-UC.06.01 [3].

The functional unit of the comparison is 1 kWh electricity consumed by the water pumps. In each case the service of the water pumps to the water distribution system of Terni is the same.

For the EV case, the goal is to investigate how the GWP and CED associated with charging the pilot EV fleet change, when charging is operated flexibly, compared with uncontrolled charging. The same three optimisation cases as for the water pump operation are investigated. The functional unit is 1 kWh of electricity delivered to the vehicles. The mobility service provided is identical in all cases, corresponding to approximately 830 vehicle-km per day for the pilot fleet.

3.4.2 Data

3.4.2.1 Foreground Data

From the use case "IT-UC.06.01" pump power data were available for the baseline operation and the three optimization cases, as well as data on PV production, electricity prices, and transformer loading, all at a 15-minute resolution over 24 hours [3]. To perform the optimization calculations of the water pumps, the actual PV production of the pilot site was increased 5 times (See Deliverable 5.1, ANNEX B – 8.3 Italian Pilot Site [3] for more details).

The data were aggregated to a 1-hour resolution, and the electricity consumption of the water pumps exceeding PV production was calculated. It was assumed that this share of electricity consumption was covered by grid electricity based on the Italian electricity generation mix for an average week in May 2026. This period corresponds to the period used to collect pilot-site-specific data for performing the flexibility optimizations (e.g. water consumption data). Figure 17 shows the pump operation power for all investigated cases and the PV production for 24 hours. Figure 18 shows for the PV optimized case additionally the grid electricity consumption.

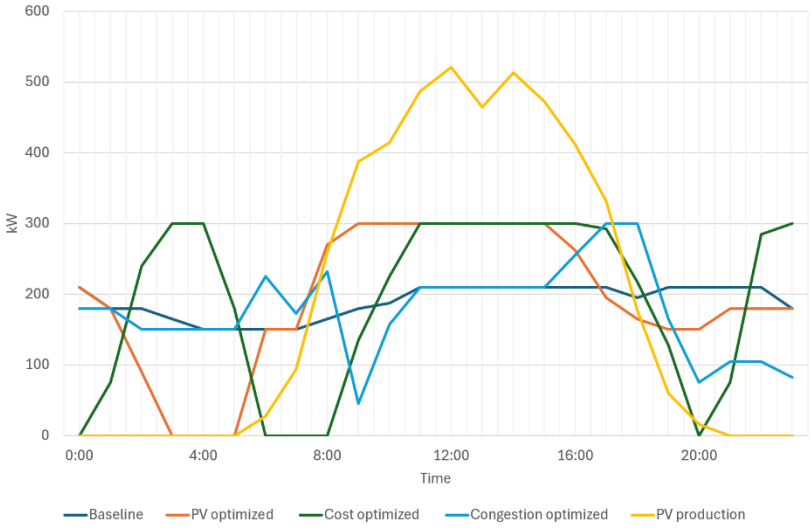


Figure 17: Pump operation power for baseline, PV optimized, Cost optimized and Congestion optimized operation for 24 hours

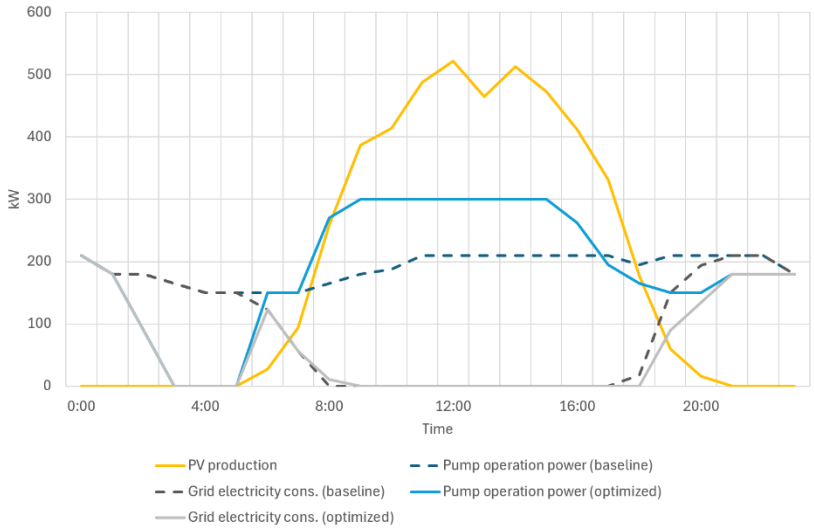


Figure 18: PV production, pump operation power (baseline + PV optimized) and grid electricity consumption (baseline + PV optimized) for 24 hours

For the EV case, hourly charging profiles over 24 hours were provided by EMOT for the baseline and the three optimisation cases (. The charging infrastructure of the pilot consists of two 22 kW AC charging points and one 50 kW DC fast charger. Total delivered energy is 150 kWh per day and is identical in all four cases: flexible charging shifts consumption in time without reducing it, since the mobility demand must still be met.

The charging profiles were modelled for the four cases, parameterised on the charging infrastructure deployed at the pilot site and on charging behaviour reported in the literature for mixed workplace and public charging sites, where uncontrolled charging aligns with the evening system peak. Measured flexible-charging data under congestion conditions were not available, since — as reported in D5.1 — no real congestion events occurred in the Italian pilot grid during the demonstration period and congestion-aware scenarios had to be simulated or adapted.

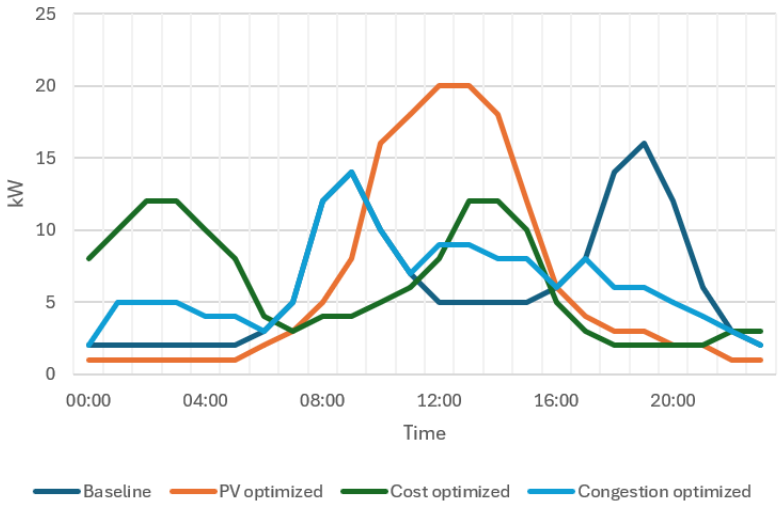


Figure 19: Modelled hourly EV charging profiles for baseline, PV optimized, cost optimized and congestion optimized case for 24 hours

To calculate the electricity generation mix for the grid electricity, data from the ENTSOE Transparency platform [10] was used. It delivered electricity mix data for an average day in May 2026 by analysing the generation per production type from the 4th to the 31st of May (4 weeks). Figure 20 shows the results. By multiplying the GWP and CED (total, non-renewable, renewable) of the production

technologies with their hourly share on the generation mix the hourly GWP and CED (total, non-renewable, renewable) per kWh grid electricity were obtained (Figure 21). Due to a higher share of solar energy and a lower share of fossil gas the emission GHG emissions and CED non-renewable per kWh electricity are lowest in the middle of the day. Based on this data the average GHG emission factor for grid electricity used in the assessment is 403 g CO_2e/kWh, with a minimum of 321 g CO_2e/kWh and a maximum of 463 g CO_2e/kWh.

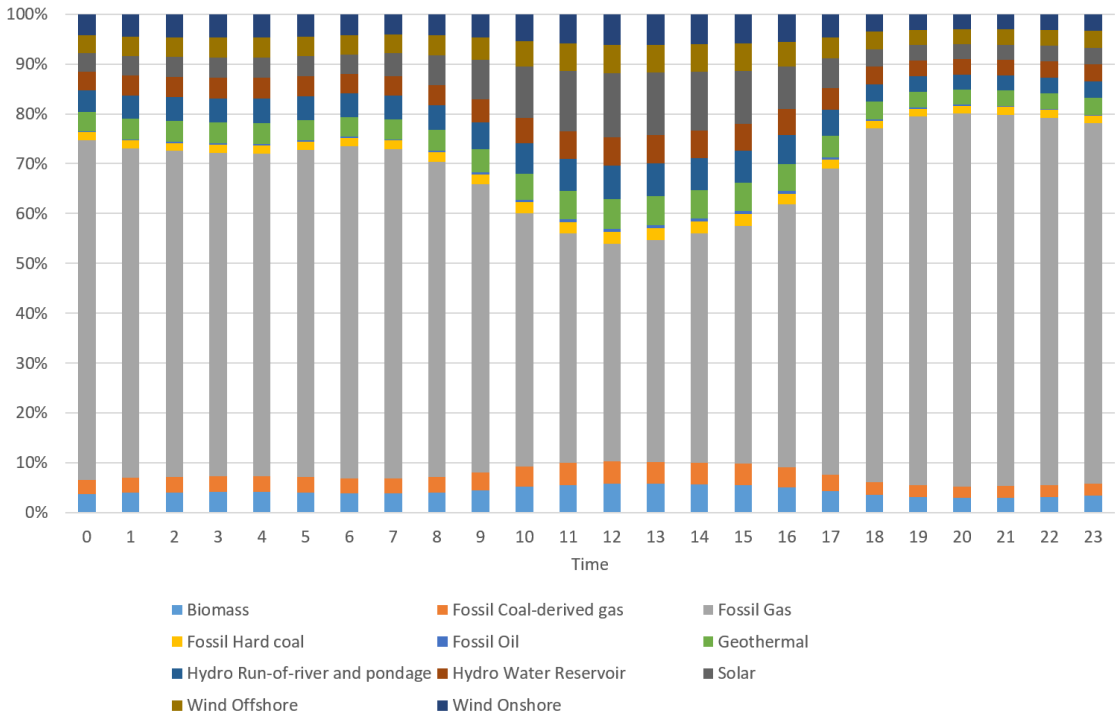


Figure 20: Italian electricity generation mix for an average day in May 2026

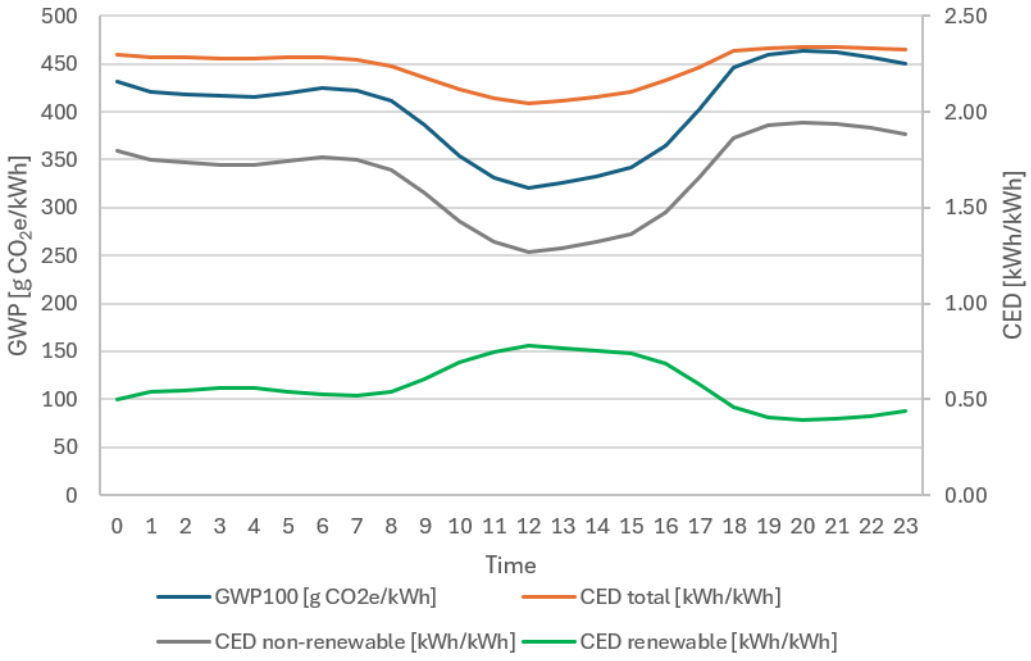


Figure 21: Hourly GWP per kWh grid electricity for an average day in May 2026

3.4.2.2 Background Data

For assessing the environmental impacts of each electricity production technology in Italy, life-cycle data has been taken from the ecoinvent 3.12 Cutoff database. The database delivered satisfying data quality for GWP and the CED (total, non-renewable, renewable) for electricity production for biomass, fossil coal-derived gas, fossil gas, fossil hard coal, fossil oil, geothermal, hydro run-of-river and pondage, hydro water reservoir, wind offshore and wind onshore. Values for photovoltaic have been derived from [11]. To consider local solar irradiation, they have been modified to the yearly energy production per kWp in Terni according to the photovoltaic geographical information system from the European Commission [12]. The obtained factors are shown in

Table 68: GWP and CEDtot, CEDnr, CEDr for electricity production from photovoltaics in Terni. Calculated by JOANNEUM RESEARCH based on [11] and [12]

	GWP [g CO2e/kWh]	CEDtot [kWh/kWh]	CEDnr [kWh/kWh]	CEDr [kWh/kWh]
PV electricity	25	1.1	0.10	1.0

3.4.3 Environmental Impact Results

The results of the LCA on GWP and CED are presented in Table 69 for the different optimization cases investigated for the water pumps. The LCA result underlines that the optimization of the local renewable self-consumption leads to the highest GWP savings (-29%) compared to the baseline operation of the pumps. Also, the other optimizations, which had different focuses as cost minimization and avoiding transformer congestion show lower GWP compared to the baseline operation. Cost optimized operation reduces the GWP by 14% and congestion optimized operation by 16%. The reason is that also for price and congestion optimized water pump operation, operation hours are moved to a certain degree to times with PV production, as shown in Figure 17.

Differences in the total CED are rather low as the system efficiency of all systems is very similar (there is no change in components only operation times of the same components are changed). However, in terms of the reduction of the non-renewable share in the PV optimized case a reduction of the non-renewable CED of almost 30% can be reached.

Table 69: GWP and CEDtot, CEDnr, CEDr for baseline and optimized operation of the water pumps

Pump operation mode	GWP [kg CO_2e/day]	CEDnr [MWh/day]	CEDr [MWh/day]	CEDtot [MWh/day]
Baseline	1,012	4.2	3.5	7.7
PV optimized	715	3.0	3.9	6.9
Cost optimized	874	3.6	3.7	7.3
Congestion optimized	846	3.5	3.4	6.9

Figure 22 shows the GWP per kWh of electricity consumed by the water pumps. For the baseline operation of the water pumps, a GHG emission factor of 222 g CO_2e per kWh of electricity consumed was determined. With PV-optimized operation, the GWP is reduced to 155 g CO_2e per kWh. Price- and congestion-based operation results in a GWP of approximately 200 g CO_2e per kWh. Due to the higher share of PV electricity in the water pump operation cases compared to the Italian electricity mix, all water pump cases have a significantly lower GWP than the GWP of approx. 400 g CO_2e of the Italian electricity generation mix for an average day in May 2026.

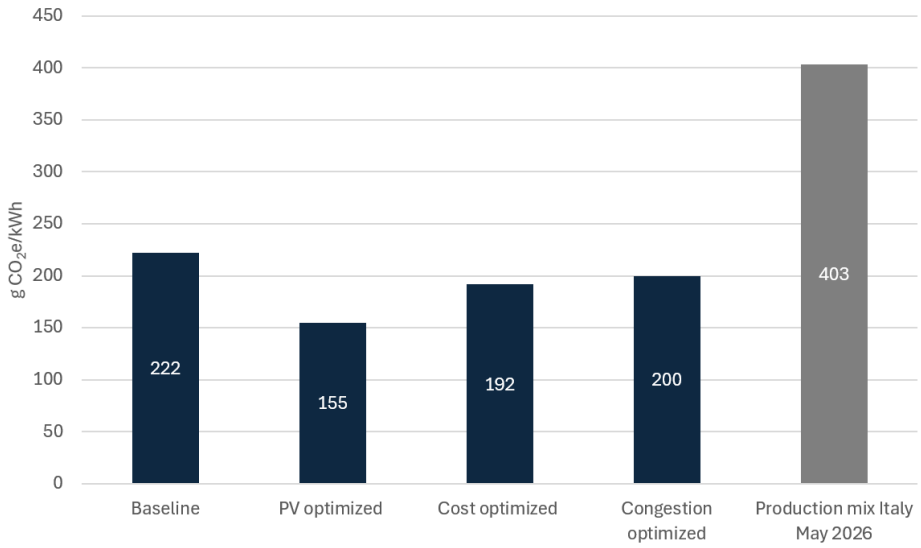


Figure 22: GHG emissions per kWh electricity consumed by the water pumps

The results on GWP and CED for the EV case are presented in Table 70. Also, for the investigated EV cases the PV optimized charging mode has the lowest GWP with 8 kg CO_2e per day. This is a reduction compared to the baseline charging profile of 40%. Cost and congestion optimized EV charging modes, however, lead to an increase in GHG emission of 130% (cost) and 30% (congestion). As shown in Figure 19 in the cost optimized cased charging is partly moved to the night, where no electricity production with PV takes place and the grid emission factor is higher. For the congestion optimized case the effect is not as strong as less energy is shifted in this case. Also, for CED the PV optimized case shows a significant benefit compared to the baseline case with the lowest total CED and the highest share of renewable energy (more than 80%).

Table 70: GWP and CEDtot, CEDnr, CEDr for baseline and optimized EV charging mode

EV charging mode	GWP [kg CO_2e/day]	CEDnr [MWh/day]	CEDr [MWh/day]	CEDtot [MWh/day]
Baseline	13	55	141	195
PV optimized	8	32	148	180
Cost optimized	31	128	120	248
Congestion optimized	18	72	72	208

Figure 23 shows the GWP per kWh of electricity consumed by the EVs. For the baseline charging mode of the EVs, a GHG emission factor of 89 g CO_2e per kWh of electricity consumed was determined. With PV-optimized operation, the GWP is significantly reduced to 53 g CO_2e per kWh. Price- and congestion-based operation results in a higher GWP of 206 and 117 g CO_2e aper kWh. Due to the higher share of local PV electricity in the EV charging modes compared to the Italian electricity mix, all EV cases have a significantly lower GWP than the GWP of approx. 400 g CO_2e of the Italian electricity generation mix for an average day in May 2026.

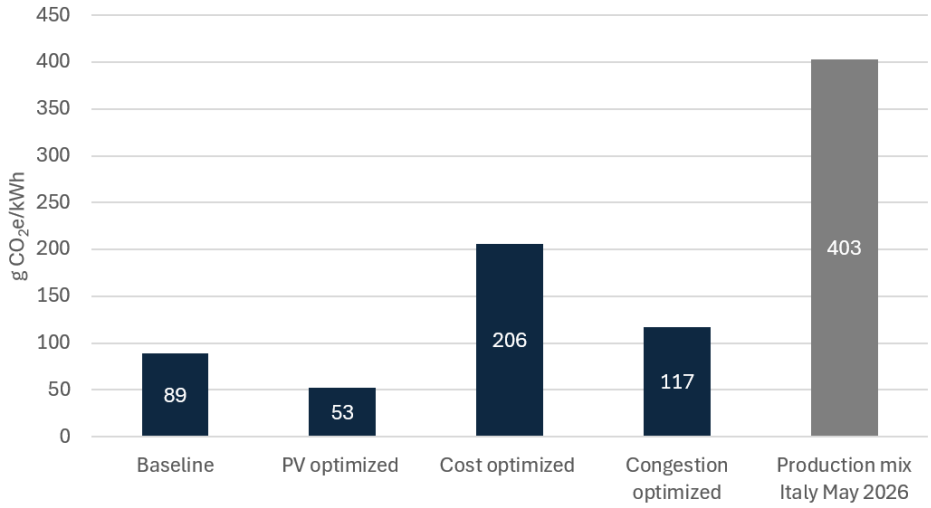


Figure 23: GHG emissions per kWh electricity consumed by the EVs

3.4.4 Conclusions

Based on results from the LCA on GWP and CED the following conclusions are drawn:

The LCA proved that optimizing water pump operation and EV charging for local PV self-consumption provides the greatest environmental benefit. For water pump operation, optimizing PV consumption reduces GWP by 29% compared with baseline operation and lowers non-renewable CED by 30%. For EV charging, both GWP and non-renewable CED are reduced by 40%.

For the water pump operation cost- and congestion-based optimization also reduce the GWP, but to a lesser extent (14% and 16%, respectively). All optimized cases achieve a substantially lower GWP per kWh electricity than the determined Italian electricity generation mix for May 2026, with PV optimization reducing it from 400 to 155 g CO_2e/kWh.

For the EV cases cost- and congestion-based optimization increased GWP, total CED and the share of non-renewable energy sources. Cost-optimized charging shifts electricity consumption to nighttime hours, when there are no local PV production and the share of fossil-based generation in the Italian electricity mix is higher. Similarly, congestion-optimized charging shifts electricity consumption to less favourable times; however, its impact is lower because less electricity is shifted. Also, here all optimized cases achieve a lower GWP per kWh electricity than the Italian electricity mix, with PV optimization reducing it to 53 g CO_2e/kWh.

The GWP and CED reduction potential of the EV use cases is higher than those of the water pump operation. This is explained as the optimization of water pump operation included technical limits as well as providing the needed function of the water pumps to the water distribution system. For the EV case the function was determined with the provision of the same transportation service of the pilot fleet in all cases and electricity consumption times were adjusted more flexible. However, limitations based on EV user behaviour are not included in the assessment, which may limit the calculated maximum potential.

3.5 FINNISH PILOT SITE

The goal of the Finnish pilot site is to offer the flexibility product FCR-D[1] to the Finnish TSO Fingrid by controllable flexible powers in the heating system. The flexibility assets consist of 6 residential apartments and three holiday cottages in different locations of Finland. Those buildings are equipped

[1] Frequency Containment Reserve for Disturbances (FCR-D); FCR-D is divided into separate upward and downward regulation products: FCR-D Up and FCR-D Down

with management system by OptiWatti, which optimizes the use of assets while maintaining proper indoor conditions.

A wide range of types of loads can be controlled through OptiWatti energy management system, including radiators, floor heating, heat pumps, hot water boilers, EV charging units. Within the project electric radiators and electric floor heating were selected as flexible loads, resulting in 58 kW controllable loads for the pilot site.

3.5.1 Goal and Scope

The goal of the LCA for Finnish pilot site is to determine how GHG emissions and CED are influenced by using the electric heating system of the buildings for flexibility provision. Therefore, two basic cases for the pilot site are evaluated: Providing space heat to the buildings with and without participating in the FCR-D market.

Figure 24 shows a simplified scheme of the Finnish pilot with the parts of the system relevant for the environmental impact assessment. In all buildings electricity is used for heating. Electricity is obtained from the electricity grid. In four houses additionally a certain share of electricity is provided via solar panels installed on the buildings. The main output of the electric heating system of the buildings is space heat. The second output of the pilot site system is the provision of FCR-D up and FCR-D down service by increasing or decreasing the electricity consumption of the heating system via the OptiWatti energy management system in combination with an additional control unit.

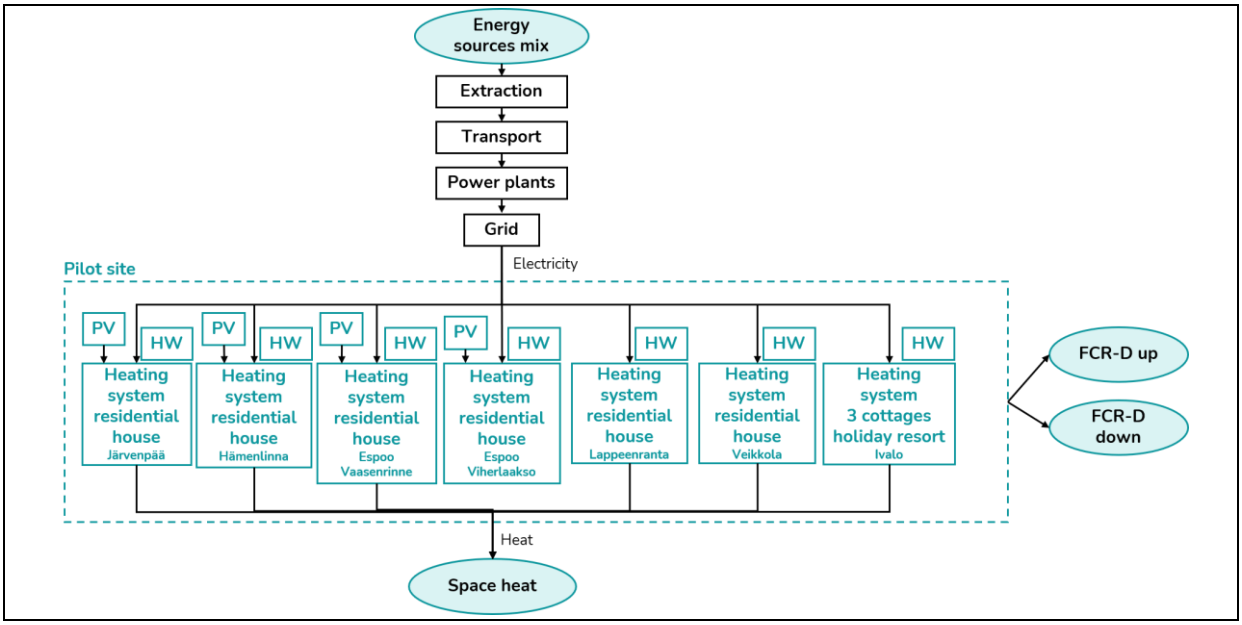


Figure 24: Simplified scheme of the Finnish pilot site for the LCA

Figure 26 shows the comparison of the pilot site with participation in the FCR-D market (Case 1) to a reference case without participation in the FCR-D market (Case 2). Both cases must provide the same services: space heat to the buildings and FCR-D up and FCR-D down. Case 1 needs additional hardware (HW) to enable the FCR-D service. In Case 2 the FCR-D service needs to be provided by another technology, here a battery energy storage system (BESS) is shown.

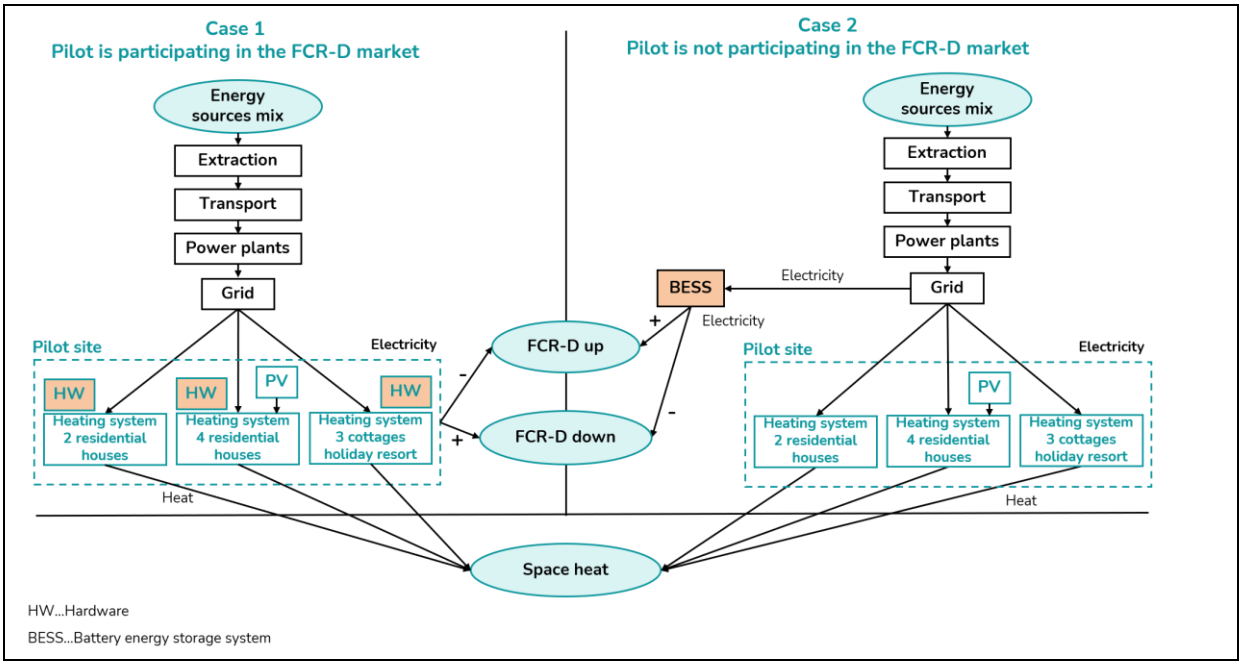


Figure 25: Comparison of the pilot case with participation in the FCR-D market (Case 1) to a reference case (Case 2)

The assessment is performed for two scales:

(1) Pilot scale: the offered FCR-D service is determined based on the pilot conditions resulting in 6.5 kW FCR-D up and 19.5 kW FCR-D down

(2) Upscaling: a minimum of 1 MW flexible load FCR-D is demanded by Fingrid to participate in the FCR-D market. Therefore, this case is also evaluated based on data OptiWatti has available from approximately 2000 other buildings. In the upscaling case 1 MW FCR D-up and 3 MW FCR-D down are investigated.

3.5.2 Data

3.5.2.1 Foreground data

To evaluate the environmental impact of the operation phase data on the energy flows of the investigated cases was needed. Therefore, data on FCR-D Services in Finland was extracted from statistical data from Fingrid [13] (Table 71).

Based on the Fingrid data, the “average duration of frequency deviations” and the” total time in a year the frequency stays outside the frequency range” has been calculated by averaging the data of the last 6 years (Table 71). Then, by using a typical load usage profile of the aggregator over one year, it has been found that a certain asset can be used for FCR-D-up at most 25% of the time since load needs to be connected in order to be cut. Since the same load cannot be used for two services at the same time, this means that the assets will be used for FCR-D-down roughly 75% of the time. Also, the removed or added load shall be proportional to the frequency deviation so not all the available load is used each time there is a frequency deviation. This leads to the result that the estimated time that a certain customer asset is used for demand-response is just 36 hours for FCR-D-down and 10 hours for FCR-D-up. By using this information as well as the estimated values of the scaling factor (the percentage of installed power that can be used in practice for flexibility), the maintained flexible power and the amount of activated energy for FCR-D up (negative value: heating system is shut down) and FCR-D down (positive value: heating is increased) were determined (Table 72). As FCR-D services are only needed for a very short period, the change in electricity consumption due to offering FCR-D

is very small compared to the total amount of electricity needed for heating (-0.3% for FCR-D up and 1% for FCR-D down).

The difference in electricity consumption for heating due to the provision of FCR-D services is so small that it was assumed that the environmental impacts of Case 1, with the provision of FCR-D services, and Case 2, without the provision of FCR-D services, are the same during the operation phase. LCA always involves uncertainties, particularly in the background data, and these uncertainties are greater than the differences in electricity consumption between the investigated cases. Therefore, the differences in the operation phase cannot be reliably assessed using LCA. Figure 26 illustrates this by showing the GHG emissions for the electricity consumption for heating at the pilot site with and without the participation at the FCR-D market.

Currently FCR-D in Finland is provided by different technologies. The following technology categories are prequalified for 2026 from Fingrid [14]:

- Energy storage,
- Consumption,
- Hydropower,
- Thermal power,
- Aggregated multiple technologies,
- Production (Nuclear, wind, solar) (for FCR-D down only).

The pilot solution is a consumption-side flexibility resource. For the environmental comparison, a lithium iron phosphate (LFP) battery is used as the storage-based reference technology which is by far the most commonly used chemistry today, due to better safety, long cycle life and competitive costs.

Table 71: FCR-Services in Finland

	FCR-D up	FCR-D down
Situation in the grid	Frequency lower than the standard range	Frequency higher than the standard range
Average duration of a frequency deviation	16.85 sec	18.35 sec
Total time in a year the frequency was outside the standard frequency range	80.30 hours	96.73 hours

Table 72: Electricity consumption for heating and FCR-D services

	Pilot-site-scale	Upscaling
Total installed power for heating	58 kW	32 MW
Total consumed electricity for heating per year	51 MWh	7116 MWh
Maintained flexible power FCR-D-up	- 6.5 kW	- 1 MW
Active energy FCR-D-up in a year	- 65 kWh	- 10 MWh
Maintained flexible power FCR-D-down	+ 20 kW	+ 3 MW
Active energy FCR-D-down in a year	+ 707 kWh	+ 108 MWh

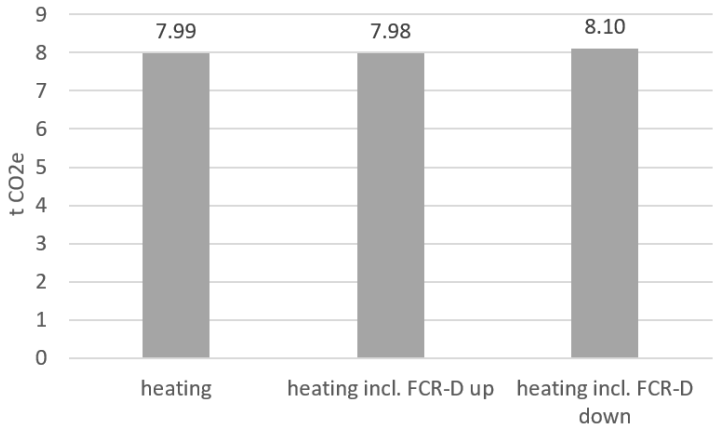


Figure 26: GHG emissions of electricity consumption for heating with and without FCR-D service at the pilot site

As mentioned above Case 1 needs additional hardware to enable the FRC-D service. In each apartment an additional smart meter needs to be installed for metering the electricity consumption at apartment level. The measurement is needed to prove on request to the TSO that power has been added or cut according to the TSO requirements, based on the related frequency variations.

For the pilot site two possible products were identified:

- Cozify HAN [15], product mass: 60 grams
- Shelly Pro 3EM 120 A [16], product mass: 62 grams

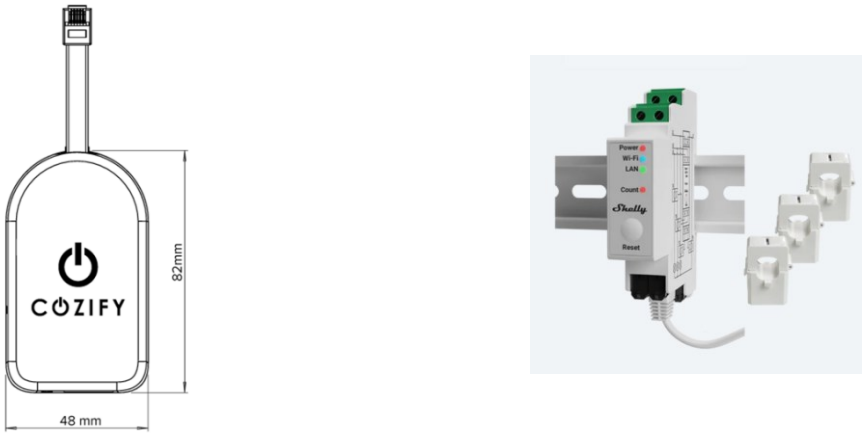


Figure 27: Cozify Han [15] and Shelly Pro 3EM 120 A [16]

Both products have similar mass. In the pilot case 10 smart meters are needed. For the upscaling case OptiWatti estimates that 400 smart meters will be needed.

The production of the smart meters for the upscaling case is compared to the production of an LFP-battery. The charging and discharging power are set at 3 MW, which corresponds to 3 MW FCR-D down in the upscaling case of the pilot site. For fast charging and discharging of a battery the C-Rate is included of 2. This leads to a storage capacity of 1.5 MWh.

For providing FCR-D, hardware is not only required for controlling units at the apartments but also for simulating the available flexible load and transferring data to servers. Information about load flexibility is transmitted several times a day for each room. FCR protocols require storage for one month at a central unit. Although this results in about 20 million data sets per year for the 400 apartments, which require continuous operation of electronic devices, the environmental impacts are estimated to be very low. The processed data consists of time steps, and Information about temperature and power, to a minor extend also about available capacities and electricity price. They can be stored and transmitted as floats, which manage with very low storage capacities resulting in total storage capacities of few gigabytes with a negligible demand for hardware.

3.5.2.2 Background data

Production of smart meters

As for both products (Cozify Han and Shelly Pro 3M 120A) no product specific information on material composition or environmental product declarations was available, datasets from ecoinvent 3.12 cutoff life cycle database were used to estimate the impact of production. Three datasets were identified:

- router, internet | router, internet | Cutoff, U - RoW
  - Internet access equipment production | internet access equipment | Cutoff, U - RoW
  - Electronics production, for control units | electronics, for control units | Cutoff, U – RoW

Production of the LFP-battery

GWP and CED factors for production of the LFP-battery are shown in Table 72 and were taken from the Argonne National Laboratory R&D-GREET model [17].

Table 73: GWP and CED – factor for battery production [17]

	GWP	CED nr	CED r	CED tot
	[kg CO2e/kWh]	[kWh/kWh]	[kWh/kWh]	[kWh/kWh]
LFP battery Production	66.7	242.5	33.5	276.0

3.5.3 Environmental Impact Results

The comparison of the pilot case, in which the heating system is used to provide FCR-D services, with a reference case without the use of the heating system for FCR-D services, as well as the analysis of the corresponding foreground data, showed that the average duration of a frequency deviation is very short (17–18 seconds) and that the total time per year during which the frequency is outside the standard range is also relatively small (80–97 hours) and the time per year a single heating asset is used for adding or cutting load is even smaller (10 – 36 hours). Consequently, the differences in the electricity consumption for heating when providing FCR-D services are very small (less than 1%).

It is also not possible to determine the influence of switching the heating system on or off on the produced space heat, as the temperature sensors do not respond to changes occurring within a matter of seconds. Therefore, no major differences in the environmental impacts of the two cases are expected during the operation phase. The minimal differences that might occur cannot be assessed using LCA, as LCA is a methodology that focuses on the life cycle of a system rather than on changes occurring over very short time intervals, such as seconds.

The only major difference between the two cases is the need for additional hardware to provide the FCR-D service. For the upscaling of the pilot-site solution, approximately 400 additional control units are required. Table shows the impacts on GWP and CED associated with the production of these control units, based on three different life cycle datasets. The GWP ranges from 0.6 to 1.3 t CO_2e, while the total cumulative energy demand (CEDtot) ranges from 2.3 to 5.0 MWh. The energy demand is mainly based on non-renewable energy sources, with a small renewable share of approximately 10%.

To put these values into perspective, they were compared with the impacts associated with the production of an LFP battery. The comparison shows that the GWP (100 t CO_2e) and CEDtot (414 MWh) of the battery are significantly higher, indicating that the environmental impact of producing the additional hardware is comparatively low. This difference can also be explained by the substantially different amounts of material required. The 400 control units have a total mass of approximately 24 kg, whereas the LFP battery (3 MW, 1.5 MWh) has a mass of approximately 11 t.

Table 74: Global Warming Potential (GWP) and cumulative energy demand (CEDnr - non renewable, CEDr - renewable, CEDtot - total) of the production of 400 control units (CU) needed in the upscaling case of the pilot solution (1 MW FCR-D up, 4 MW FCR-D down) and of the production of a LFP battery (3MW, 1.5 MWh)

	GWP	CEDnr	CEDr	CEDtot
	[t CO_2e]	[MWh]	[MWh]	[MWh]
HW (Dataset 1 - router)	1.3	4.5	0.6	5.0
HW (Dataset 2 - internet access equ.)	0.6	2.0	0.3	2.3
HW (Dataset 3 - electronics for CU)	0.8	2.9	0.4	3.3
LFP battery (3 MW, 1.5 MWh)	100	364	50	414

3.5.4 Conclusions

Based on the results of the environmental impact assessment on GWP and CED the following conclusions are drawn:

The provision of FCR-D services has a negligible impact on the operation of the heating system. The short duration of frequency deviations results in less than a 1% difference in electricity consumption for heating, with no major impact on the provision of space heat or the operational environmental impacts.

The main additional environmental impact of providing FCR-D services is associated with the production of the required additional smart meters. For the upscaling of the pilot-site solution, approximately 400 units are required, resulting in a GWP of 0.6–1.3 t CO_2e and a CEDtot of 2.3–5.0 MWh. However, the environmental impact of the additional device is very low compared with that of battery-based solutions.

3.6 CROSS-PILOT SYNTHESIS OF THE ENVIRONMENTAL EVALUATION

In all four pilots in Slovenia, Spain, Italy and Finland, results for Global Warming Potential and Cumulative Energy Demand show that the biggest environmental benefit of flexibility solutions is due to enabling an increase of renewable electricity consumption in the local grid, which often substitutes electricity imported from the transmission grid with a remaining share of fossil energy carriers. This proves that STREAM flexibility solutions directly contribute to EU Decarbonization Goals (Fit for 55). Compared to the impact of the electricity, the impact of required hardware infrastructure installations and operation for enabling STREAM flexibility solutions, such as BESS, local grid upgrade or controllers and ICT / Cloud infrastructure of flexible consumers, have an almost negligible impact. A similar conclusion applies to technical hardware such as grid upgrade without flexibility solutions with the same objective to raise the share of PV electricity consumed in the local grid. When comparing the environmental impacts of the installation of flexibility solutions only, without considering the electricity supplied, the results in the four demos show the following order, starting with the lowest impacts:

- Flexible consumers, such as heat pump, electric vehicles, water pumps or heating systems (see pilot sites in Slovenia, Finland, Italy)
- Local grid upgrade (see pilot sites in Slovenia and Spain)
- Battery BESS (see pilot site in Spain and Finland)

Flexible consumers require hardware controllers installed at the consumers and ICT / Cloud infrastructure for transferring data to servers and storing FCR protocols. Related environmental impacts were estimated to be very low (controller mass a few grams, data transfer and storage capacity of a few gigabytes) in the Finnish pilot site. The operation of flexible consumers can be optimized based on different objectives. Results of the Italian pilot site show that the objective of maximizing the share of PV electricity consumed in the local grid results in the highest environmental benefits, whereas the objective of maximizing economic value can result in increasing environmental impacts. Local grid upgrades show to have lower environmental impacts than battery storage in the Spanish pilot site, as grid hardware such as cables and transformers have a longer lifetime and lower losses during operation compared to battery storage.

4 SOCIAL IMPACT ASSESSMENT

The social impact assessment evaluates how the STREAM solutions and services are perceived and experienced by the users and stakeholders involved in the four pilot sites. General social KPIs are used for all pilots and are complemented by pilot-specific social indicators covering aspects such as energy literacy, motivation, convenience, comfort, trust, control, operational feasibility and perceived barriers.

The assessment reflects the different characteristics of the pilot sites and participant and stakeholder groups. Household survey results are reported descriptively using means and standard deviations, while industrial and water-sector responses are mainly presented as response counts.

Pilot-level and cross-pilot conclusions focus on the social benefits, barriers and potential adverse effects supported by the available results. Because the survey instruments and sample sizes differ between pilots, the results are not used for direct numerical comparison or generalised beyond the participants assessed. Cross-pilot interpretation instead identifies recurring themes and differences that may influence participation in and acceptance of flexibility services.

4.1 LIST OF SOCIAL KPIS, INDICATORS AND METHODOLOGY

The social assessment uses formal social KPIs where defined and complements them with the validated social indicators collected through STREAM's user-centred and stakeholder-engagement activities [1, 3]. For the assessment online surveys have been used. These were developed based on established constructs from the fields of technology acceptance, usability, trust in automation, service convenience, motivation, energy behaviour and energy literacy.

The selection and formulation of items were further discussed with the respective pilot sites to ensure their relevance to the specific user groups, contexts, and stage of implementation. Given the varying characteristics of the pilot sites, the surveys were not designed as a uniform instrument, but rather tailored to reflect the topics most relevant to each context.

In household-oriented Pilot sites, particular emphasis was placed on convenience, comfort, ease of integration into everyday routines, and trust in the flexibility system. For industrial applications, greater attention was given to safety, reliability, operational impacts, and the integration of flexibility services into existing industrial processes. The surveys also consider different forms of motivation, including financial incentives as well as social, environmental, and collective benefits. This approach allows the surveys to capture both, user acceptance across pilot sites and context-specific concerns that may influence participation in flexibility services. The survey items were formulated as statements and assessed using five-point Likert scales ranging from *completely disagree* to *completely agree*. The results are reported using means and standard deviations, both at the individual item level and, where applicable, at the level of the respective dimensions. Due to the relatively small sample sizes at the individual pilot sites, the findings should not be interpreted as statistically representative or generalisable to the wider population. Rather, the results reflect the perceptions and experiences of the specific participants included in the assessment. In the industrial pilots, the survey results are particularly intended to provide insights into potential barriers and challenges associated with the implementation and integration of flexibility services in an industrial context. The findings therefore provide an initial indication of aspects that may require further consideration, adaptation, or clarification in the design and implementation of the services. Similarly, results from the household pilots provide an initial indication of users' perceptions. The reported means and standard deviations should consequently be interpreted descriptively rather than as estimates of population parameters. Given the exploratory nature of the assessment and the limited sample sizes, no conclusions about the prevalence of specific perceptions or potential barriers in the broader target population can be

drawn. Nevertheless, the findings can support the identification of recurring themes and inform potential improvements to the flexibility services.

Table 75: Social evidence sources and interpretation boundaries

Pilot / group	Evidence	Sample / scale	Interpretation boundary
Slovenian industrial	Structured industrial questionnaire	4 organisations / respondents	Organisational perceptions; item-level response counts
Spanish household / community	Structured survey	n=40; 1-5 scale	Descriptive sample statistics; some items phrased prospectively
Italian household / EV user	Structured survey	n=6; 1-5 scale	Small household sample; descriptive only
Italian water sector	Structured questionnaire	n=2	Essential-service operator perceptions and barriers
Finnish household	Structured survey	n=3; 1-5 scale	Very small sample; descriptive only

4.2 SLOVENIAN SOCIAL IMPACT

The Slovenian social evidence represents four industrial participants and focuses on trust, motivations, operational integration, safeguards, governance and market usability. Because of this limited sample size, the findings are treated as qualitative insights rather than statistically generalizable quantitative data. Responses are structured around a 5-point Likert scale ranging from *disagree* to *completely agree* (alongside options for neutral/neither and "not familiar / prefer not to answer")

4.2.1 Trust, Transparency and Control

Respondents strongly agree on the necessity of clear rules on data ownership, use, and cybersecurity (completely agree: 3, neither agree nor disagree: 1). There is also a firm requirement for the ability to override or opt out of flexibility activation when needed (agree: 3, completely agree: 1) and a shared belief that clear feedback on when and how flexibility is activated increases our trust (completely agree: 2, agree: 2).

4.2.2 Strategic Goals and Sustainability

There is strong alignment around high-level objectives, with respondents noting that supporting grid stability and energy system resilience is important for their company (completely agree: 2, agree: 2) and supporting more efficient use of energy and renewable resources through flexible energy use is important for their company (completely agree: 2, agree: 2). Participants also indicate that participation helps our company prepare for future energy, grid, and regulatory changes (agree: 2, neither agree nor disagree: 2) and that participation in a local flexibility market aligns with our company's sustainability and energy transition goals (completely agree: 1, agree: 1, neither agree nor disagree: 1, not familiar / prefer not to answer: 1).

4.2.3 Operational Impact and Feasibility

Participants highlight that clear guarantees are needed to protect production quality, safety, and equipment lifetime (completely agree: 3, agree: 1). Furthermore, respondents feel that connecting their equipment to a flexibility platform is technically feasible (agree: 2, completely agree: 1, neither agree nor disagree: 1), flexibility activation can avoid production peaks or critical operations (agree:

2, completely agree: 1, neither agree nor disagree: 1), and participation does not require excessive administrative or reporting work (completely agree: 2, agree: 1, neither agree nor disagree: 1). However, views are slightly more mixed regarding whether flexibility services can be integrated without disrupting core operations (agree: 2, disagree: 1, neither agree nor disagree: 1)

4.2.4 Values, Incentives and Reputation

Regarding secondary benefits, respondents agree that participation in innovative energy initiatives improves their position and reputation (agree: 3, neither agree nor disagree: 1), participation could help improve internal energy efficiency or operational planning (agree: 3, neither agree nor disagree: 1), and a simple and transparent local flexibility market makes participation more attractive (agree: 3, completely agree: 1). Meanwhile, motivations around having access to and helping to advance digital platforms (agree: 2, neither agree nor disagree: 2), providing flexibility services could reduce energy costs or create financial benefits (agree: 2, neither agree nor disagree: 1, not familiar / prefer not to answer: 1). Furthermore, public recognition positively influenced their willingness to participate (agree: 2, disagree: 1, not familiar / prefer not to answer: 1) show more diverse or cautious engagement.

4.2.5 Key Barriers Analysis

Operational risks to core production represent the primary shared obstacle for these industrial participants. Contract complexity and fixed schedules are dismissed as major barriers, suggesting that organizational reluctance centres on business safety rather than administrative or scheduling constraints. Technical integration presents a low barrier, while financial, regulatory, expertise, and security concerns remain highly subjective across the limited sample.

- Primary Operational Risk: 3 out of 4 participants cite *Risk to core operations or production* as a recognized barrier, making it the most dominant concern for active participation.
- Zero-Consensus Barriers: Limited flexibility due to fixed schedules and complex contracts or market rules were rejected by all 4 participants (4 "No" votes), indicating these are not seen as active constraints within this sample.
- High Integration Effort: 3 out of 4 respondents do not consider high technical integration effort to be a barrier, while 1 views it as an issue.
- Participants were evenly split (2 "Yes", 2 "No") across five distinct areas:
- Uncertain financial benefits
- Lack of internal time or expertise
- Data privacy or cybersecurity concerns
- Unclear regulation or legal framework
- Insufficient non-monetary incentives

4.2.6 Additional social challenges, adverse impacts and mitigation

Additional Slovenian social challenges arise where flexibility could conflict with production continuity, equipment safeguards, data governance or operational autonomy. The strongest protective signals in the questionnaire are the demand for clear production/safety guarantees, cybersecurity and data-ownership rules, override/opt-out capability and a simple, transparent market process.

4.3 SPANISH SOCIAL IMPACT

The Spanish survey contains 40 participants (15 female, 22 male and 3 diverse), aged 30-81 years (mean 61.6), with varied education and housing types (27 apartment, 12 detached houses, 1 finca - *a traditional Spanish rural estate, farm, or country house set on a large plot of agricultural or woodland land*). Findings are interpreted as

qualitative insights within this sample rather than generalizable population estimates. Responses are evaluated on a 5-point Likert scale ranging from disagree to completely agree (alongside options for neutral/neither and not familiar / prefer not to answer).

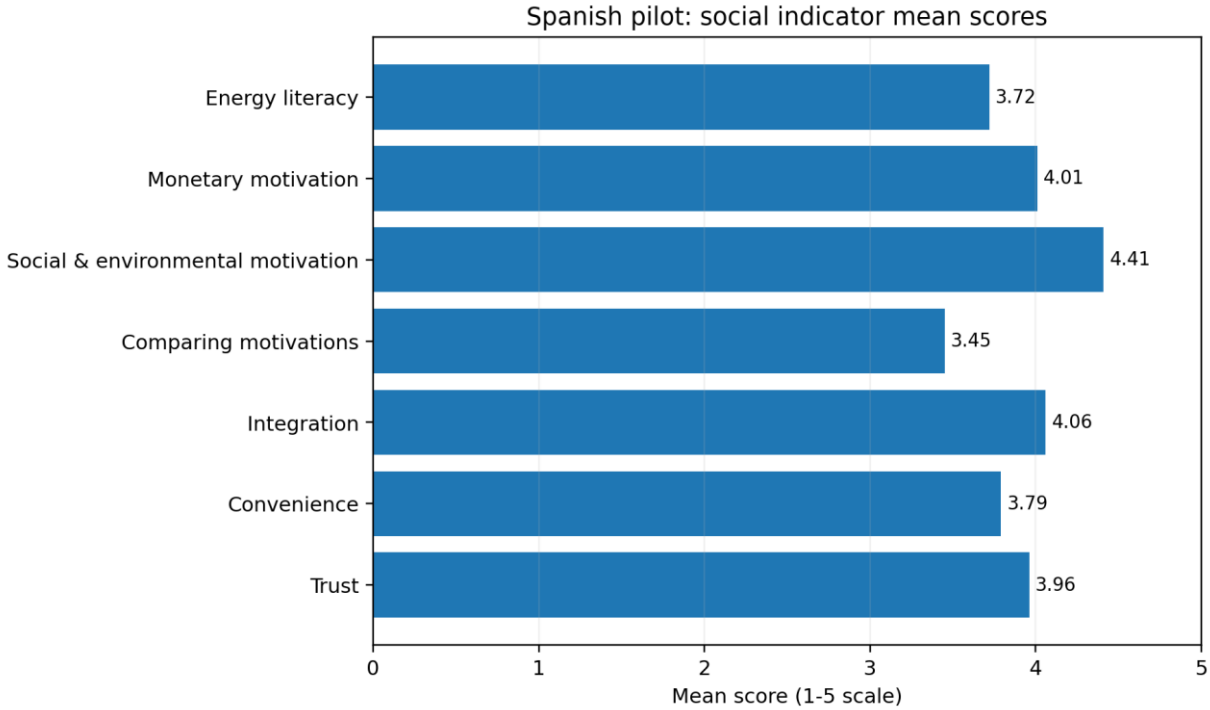


Figure 28: Spanish pilot social indicator mean scores

4.3.1 Energy Literacy

Energy Literacy is reported on the source 1-5 scale. **Mean = 3.72, SD = 0.95.** Participants reported a moderately high understanding of electricity production, delivery and household demand.

4.3.2 Monetary Motivation

Monetary Motivation is reported on the source 1-5 scale. **Mean = 4.01, SD = 0.76.** Financial rewards are an important participation motive, although the lower agreement with only participating for money indicates that they are not the sole motive.

4.3.3 Social and Environmental Motivation

Pro-social and environmental values represent the strongest motivation overall (M = 4.41, SD = 0.64). Participants expressed high agreement around community benefits (M = 4.47), personal responsibility for sustainability (M = 4.42), and grid stability (M = 4.32).

4.3.4 Comparing Motivations

Comparing Motivations is reported on the source 1-5 scale. **Mean = 3.45, SD = 0.78.** The combined score indicates a slight tendency toward financial incentives while retaining meaningful value for non-monetary benefits.

4.3.5 Integration

The FLEXIBILITY system scores high on operational integration (M = 4.06, SD = 0.67), reflecting low required effort (M = 4.15), high ease of living with the technology (M = 4.10), good fit with daily energy use (M = 4.05), and minimal negative impact on well-being (M = 3.92).

4.3.6 Convenience

Perceptions of convenience are moderately positive (M = 3.79, SD = 1.05). The system generally avoids disrupting daily routines (M = 3.82) or reducing living comfort (M = 3.77), though higher standard deviations point to individual variability depending on living conditions.

4.3.7 Safety Security / Trust

Trust in the system is high (M = 3.96, SD = 0.78). Confidence is strongest regarding personal data protection (M = 4.21), alongside positive agreement regarding prevention of unauthorized control (M = 3.97), automated coordination safety (M = 3.92), general device coordination safety (M = 3.92), and system reliability (M = 3.84).

4.3.8 Open feedback, additional social challenges and mitigation

The single Spanish open comment expresses uncertainty about external management of electrical devices and whether its effect would be positive or negative. This supports the need for plain-language explanations of what is controlled, when activation can occur, what information is visible to the participant and how control can be overridden. The sample spans ages 30-81, but the evidence does not establish an age-related difference in digital access or acceptance.

4.4 ITALIAN HOUSEHOLD AND EV-USER SOCIAL IMPACT

The Italian household/EV-user survey contains six male participants aged 30-51 years (mean 41.0). Four live in apartments and two in detached houses. The evidence is descriptive for this small sample and includes an open concern about possible EV-battery effects from energy exchange. Findings are interpreted as qualitative insights within this sample rather than generalizable population estimates. Responses were evaluated on a 5-point Likert scale ranging from disagree to completely agree (alongside options for neutral/neither and not familiar / prefer not to answer).

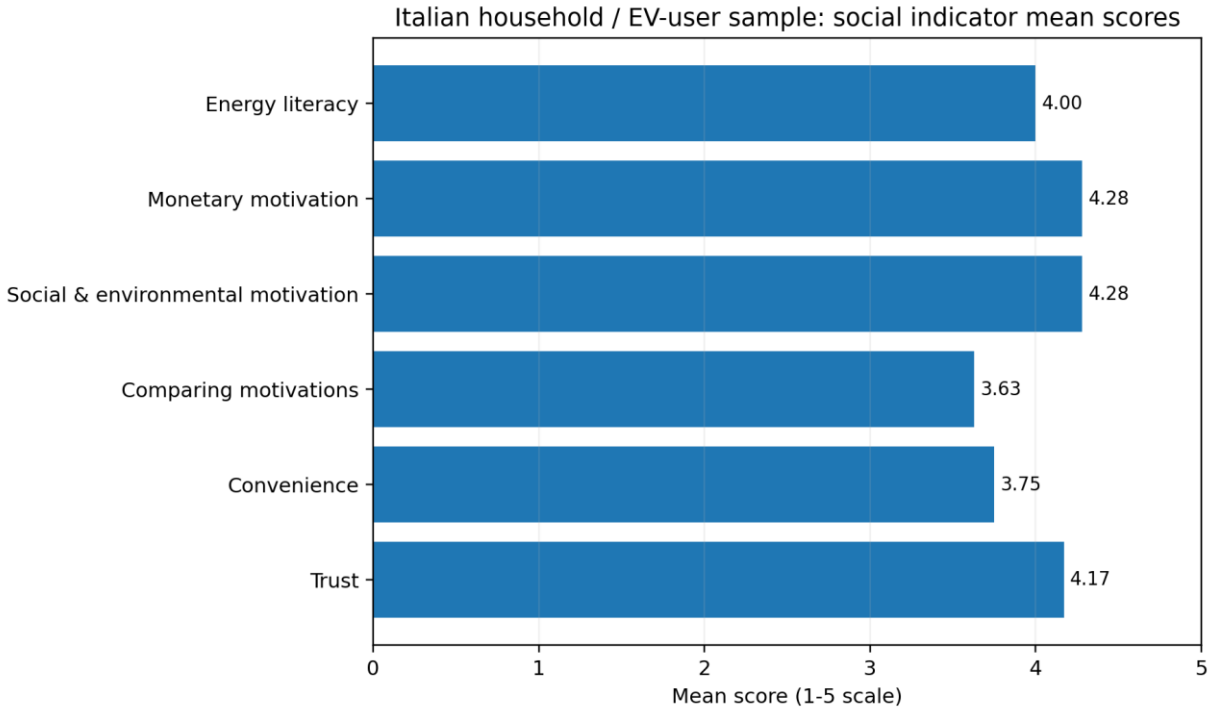


Figure 29: Italian household and EV-user social indicator mean scores

4.4.1 Energy Literacy

Energy Literacy is reported on the source 1-5 scale. **Mean = 4.00, SD = 0.84.** The household sample reports a moderately high understanding of electricity production, delivery and household demand.

4.4.2 Monetary Motivation

Monetary incentives represent a primary motivator (M = 4.28, SD = 0.44). Participants strongly agree that adjusting usage is worth the compensation (M = 4.67) and serves as a primary driver (M = 4.33), though lower agreement on participating exclusively for financial gain (M = 3.83) shows money is essential but not sole motivation

4.4.3 Social and Environmental Motivation

Pro-social and environmental factors act as an equally strong motivator (M = 4.28, SD = 0.53). Supporting grid stability emerged as the single highest-rated item overall (M = 4.83), paired with high personal responsibility for sustainability (M = 4.67) and community benefits (M = 4.33).

4.4.4 Comparing Motivations

The comparison score leans toward financial motivation but has substantial response variability (M = 3.63, SD = 1.20).

4.4.5 Convenience

Perceptions of system convenience are moderately positive (M = 3.75, SD = 0.42). Respondents indicate that the system does not noticeably reduce living comfort (M = 3.83) or disrupt daily routines (M = 3.67).

4.4.6 Safety Security / Trust

Trust in the system is high (M = 4.17, SD = 0.34). Participants express strong feeling of safety regarding device coordination (M = 4.33), paired with solid confidence in data protection (M = 4.17), automated coordination safety (M = 4.17), prevention of unauthorized control (M = 4.17), and general reliability (M = 4.00).

4.4.7 Open feedback, asset-lifetime concerns and mitigation

The Italian household/EV-user open feedback raises a specific concern about whether energy exchange could increase charging cycles, damage the EV battery or reduce its lifetime. This is a qualitative adverse-impact signal relevant to perceived asset control and technology acceptance.

Mitigation should therefore focus on transparency and user control. Participants should be clearly informed about:

- how charging schedules may be modified,
- the operating limits applied to the vehicle, including state-of-charge limits,
- and any potential implications for battery degradation or warranty conditions.

Information should also cover the use of vehicle and charging data, the basis for any remuneration, and the possibility to opt out or override flexibility activation where applicable. The demonstration showed that EV charging schedules can be adapted in response to grid needs without fully interrupting charging and that delivered flexibility can be validated and remunerated. However, the available results do not quantify battery degradation or establish formal warranty, state-of-charge or opt-out safeguards. These aspects should therefore be treated as implementation conditions.

4.5 ITALIAN WATER-SECTOR SOCIAL IMPACT

The Italian water-sector questionnaire contains two respondents and addresses essential-service continuity, hydraulic operation, asset lifetime, accountability, regulatory alignment and perceived barriers. The findings should be interpreted with caution, as the survey was completed by only two respondents and therefore cannot be considered generalizable.

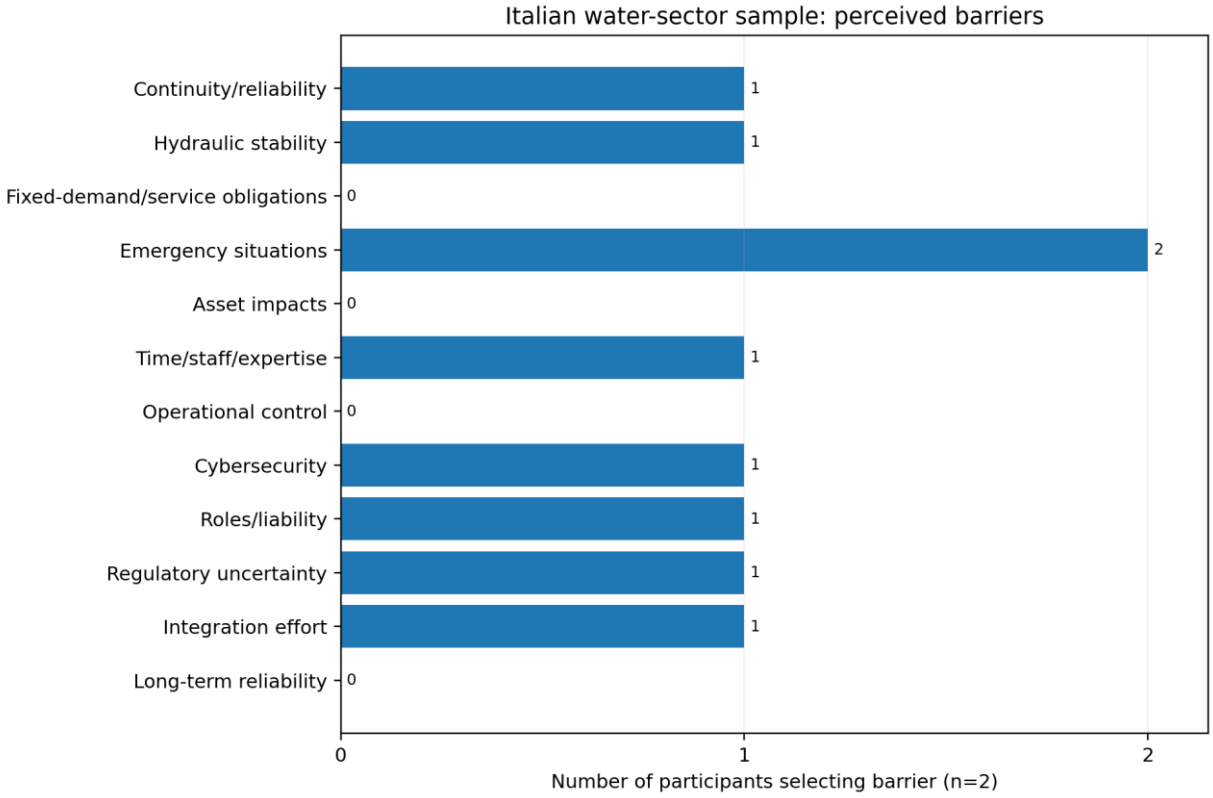


Figure 30: Italian water-sector perceived barriers

4.5.1 Safe and continuous water supply

Both respondents agreed that the flexibility system supports coordinated planning of safe and continuous water supply under normal and peak-demand conditions. The two responses support compatibility with continuity objectives at the perception level.

4.5.2 Interruption and pressure-drop risk

Both respondents agreed that the proposed coordination measures do not increase the risk of supply interruptions or pressure drops. Continuity and pressure concerns were not reported as direct adverse effects of the proposed approach in this two-person sample.

4.5.3 Operational control over pumping, tanks and pressure

One respondent was neutral and one completely agreed that the water operator retains sufficient control over pumping schedules, tank levels and pressure management. The split response makes retained operator control an important implementation condition.

4.5.4 Planned coordination and stable operation

Both respondents agreed that flexibility actions are planned and coordinated in a way that supports stable system operation. Planned coordination is perceived as compatible with stable water-system operation.

4.5.5 Safe implementation under variable hydraulic and demand conditions

One respondent was neutral and one agreed that flexibility can be safely implemented under variable hydraulic and demand conditions. The mixed response supports cautious interpretation under changing operating conditions.

4.5.6 Pump, valve and critical-asset lifetime

Both respondents agreed that flexibility measures would not negatively affect the lifetime or reliability of pumps, valves or other critical assets. No perceived asset-lifetime penalty is indicated by the two respondents.

4.5.7 Roles, responsibilities and accountability

One respondent agreed and one completely agreed that roles and responsibilities between the water operator and other flexibility-coordination parties are clearly defined. Responsibility clarity is positively perceived by both respondents.

4.5.8 Regulatory and operational-standard alignment

One respondent agreed that the approach is aligned with water-sector regulations and operational standards and one gave no answer. The single substantive response is positive, but the evidence base is one respondent for this item.

4.5.9 Perceived Barriers

Potential barriers were presented and ticked by the respondents in case they were perceived as such. Concerns on operating the flexibility system in emergency situations (fires, droughts or infrastructure failures) was selected by both respondents. Risk of continuity/reliability, hydraulic stability, lack of staffing/expertise, cybersecurity, unclear roles or legal liability, regulatory uncertainty and integration effort were each selected by one respondent. No concerns were reported in regard to limitations on operational flexibility and the long-term reliability of the flexibility system. The main barrier, perceived by both respondents addresses emergency-operation safeguards, with secondary concerns distributed across technical, governance and resource themes.

4.5.10 Additional social challenges, adverse impacts and mitigation

The water-sector evidence identifies emergency situations as the most prominent perceived barrier, selected by both respondents. One respondent also selected each of continuity/reliability, hydraulic stability, staffing/expertise, cybersecurity, unclear roles/liability, regulatory uncertainty and integration effort. These responses identify the operational conditions that must be protected when flexibility is coordinated with an essential service. The main water-sector risks are already addressed through operational safeguards embedded in the pilot approach. Maintaining water supply takes priority over flexibility provision, and the flexibility assessment and scheduling logic respect reservoir limits, expected water demand and pump operating constraints. During the demonstrated real-life activation, the pumping station remained under operator supervision and automatic control was restored after the flexibility period. The reservoir provided a buffer that allowed electricity consumption to be shifted without interrupting the water supply. These measures reduce the risk that flexibility activation affects service continuity or hydraulic operation. However, the demonstration covered only a supervised activation and does not establish performance under the full range of demand, hydraulic or emergency conditions.

4.6 FINNISH SOCIAL IMPACT

The Finnish social framework contains two formal KPIs, FI.04 Customer answer rate and FI.06 Customer satisfaction, followed by source-defined questionnaire scales on energy literacy, motivation, integration, comfort and trust [3]. The available questionnaire report covers three private households, one semi-detached and two detached house.

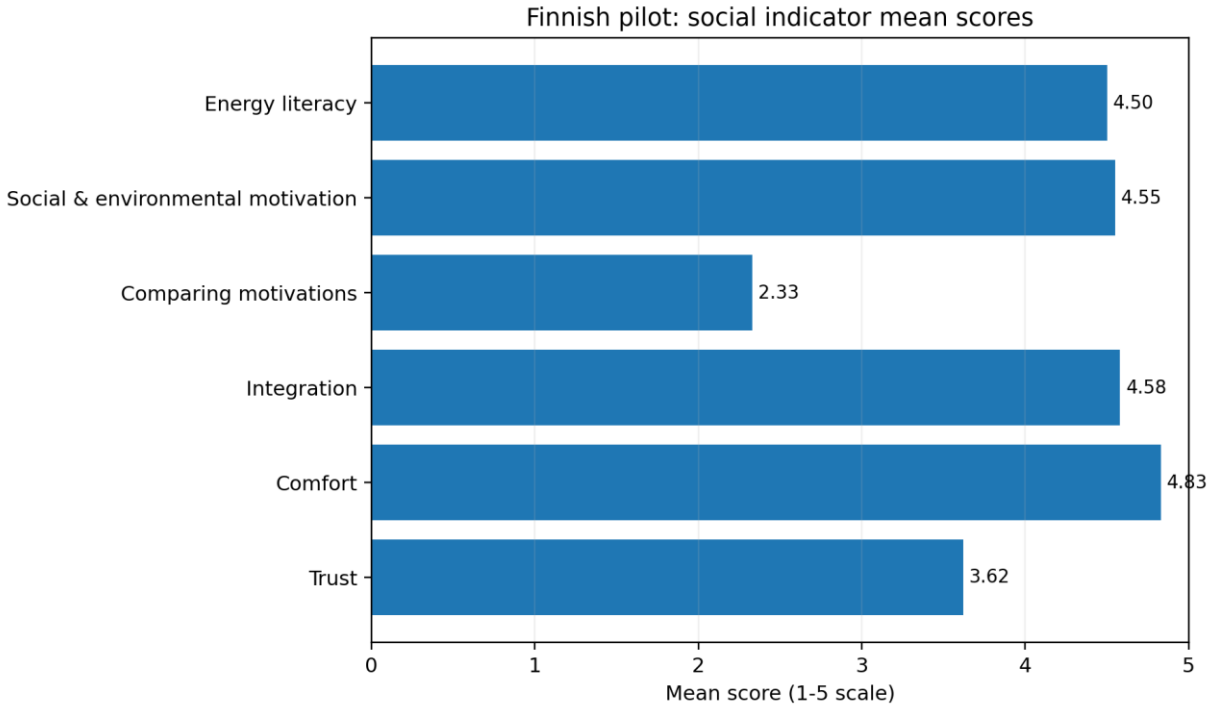


Figure 31: Finnish pilot social indicator mean scores

4.6.1 FI.04 - Customer answer rate

Customer answer rate measures the proportion of eligible questionnaire recipients who submitted an answer:

$$Customer\ answer\ rate\ (\%) = \frac{amont\ of\ answered\ questionnaires}{amont\ of\ sent\ questionnaires} * 100$$

Equation 45: FI.04 customer answer rate

The unit is percentage **(%)**. FI.04 is associated with UC FI.04, User experience when using flexibility. It is reported as one aggregate value for the Finnish pilot.

Based on the latest documented count available to VTT, eight questionnaires were sent and three were answered, thus giving value FI.04=37,5 %. The formal target was 50%, which means the research achieved 75 % of the target.

The Finnish pilot questionnaire was a short customer-feedback questionnaire concerning the impact of using customers' heating assets as flexible load. It was distributed by email just after test period ended at 8.5.2026. One reminder was sent 19.5.2026 and reminded also in pilot customer workshops 29.4.2026 and 15.6.2026. 8 eligible questionnaires were sent (10 apartments, but 3 of them of one owner). The questionnaire covered perceived temperature deviations, other discomfort such as relay noise, overall experience on a five-point satisfaction scale, and an open comments field.

FI.04 should be interpreted as an indicator of the reach and completeness of the social assessment, not as an indicator of customer satisfaction. A response rate of 37.5% means that feedback was

obtained from fewer than four out of every ten eligible questionnaire recipients. Consequently, the survey provides direct evidence about the experiences of respondents, but incomplete evidence about the full eligible pilot population.

Customer satisfaction is measured separately through the respondents' ratings under FI.06. The project material defines customer satisfaction as the average of the individual overall-satisfaction scores on a scale from 1 to 5. FI.04 therefore answers "How much of the intended participant population was represented in the questionnaire evidence?", whereas FI.06 answers "How did the respondents rate their experience?".

The principal limitation is non-response bias. If customers who answered differed systematically from non-respondents, for example in engagement, availability, technical experience or strength of opinion, the respondents' satisfaction and comfort observations may not represent all pilot customers. With only three responses, individual answers also have a large influence on averages and distributions. Results should therefore be presented descriptively as respondent feedback, without generalising them to all Finnish pilot customers.

The Finnish pilot did, however, maintain broader engagement through regular online customer meetings. Ten online pilot-customer meetings until now intended to maintain engagement, provide status updates and receive feedback. Workshop observations can provide contextual qualitative evidence, but they should not be merged into the FI.04 numerator or treated as questionnaire responses unless the methodology explicitly defines them as such.

Based on the Finnish pilot experience, the following improvements are recommended:

1. Earlier communication of survey importance. Present the evaluation process already during the pilot workshops and explain how questionnaire responses contribute to project outcomes and future services.
2. Survey completion during workshops. Allocate time during the final customer workshop for participants to complete the questionnaire immediately instead of relying exclusively on later e-mail responses.
3. Mixed-method feedback collection. Complement online questionnaires with short structured interviews. This possibility was already discussed within the WP6 team and would improve coverage in small pilot populations.
4. Follow-up contacts to non-respondents. In small pilot populations a personal phone call or direct contact may be more effective than generic reminder e-mails.
5. Continuous rather than single-point feedback. Collect short feedback after major milestones and workshops instead of relying solely on a final questionnaire at project completion.

4.6.2 FI.06 - Customer satisfaction

FI.06 Customer Satisfaction measures the overall satisfaction of pilot participants with the flexibility service and their experience during the demonstration period. FI.06 is calculated as the average of the overall satisfaction scores provided by respondents, where satisfaction is rated on a 5-point scale ranging from 1 (very dissatisfied) to 5 (very satisfied). The KPI therefore expresses the questionnaire item: "How would you rate your experience during the trial period by using a scale from 1 to 5, where 1 is 'very dissatisfied' and 5 is 'very satisfied'?". This overall experience rating is the item used for the FI.06 calculation. It should not be confused with the separate questionnaire dimensions measuring comfort, integration into daily life, trust, or motivation, which are reported as distinct social indicators.

The approved calculation method is:

$$FI.06 = \frac{\sum Overall\ satisfaction\ scores}{n}$$

Equation 46: FI.06 customer satisfaction

where n is the number of valid respondents.

No formal FI.06 target value or benchmark was identified in the reviewed Finnish pilot documentation.

The Finnish social KPI report shows that the dimensions of integration, comfort, trust and motivation were evaluated separately and achieved different scores. For example, comfort and integration received very high ratings, while trust-related ratings were somewhat lower. Therefore, FI.06 should be interpreted as an overall experience indicator rather than a substitute for any of these individual dimensions.

Two approaches were used in evaluating the overall satisfaction:

1. Based on **questionnaire**: The overall satisfaction score was not asked in the web questionnaire. Overall satisfaction was calculated as average of 5 sectors (energy literacy, social and environmental motivation, comparing motivations, integration, comfort and Safety/security and trust, which doesn't exactly measure the overall satisfaction. Based on method 1, FI.06= 4,1.
2. Based on **email interview**: Email was sent to pilot customers to ask only the question: How would you rate your experience during the trial period on a scale of 1–5, where 1 means "very dissatisfied" and 5 means "very satisfied"? 6 of 7 pilot customers replied. Based on method 2, FI.06=4,00 (SD=0,89)

4.6.3 Energy Literacy

Participants reported a high level of energy literacy (**Mean = 4.50, SD = 0.50.)**, indicating that they generally understand how electricity is produced, distributed, and consumed. This was not surprising results due to voluntary participation.

4.6.4 Social and Environmental Motivation

Community benefit, sustainability responsibility and grid stability are strong reported motives (**Mean = 4.55, SD = 0.38)**. Users show strong social and environmental motivation to participate, indicating that community benefit, sustainability responsibility, and grid stability are key drivers, suggesting that emphasizing these values can effectively support user engagement.

4.6.5 Comparing Motivations

Financial incentives are given relatively low importance compared with non-monetary benefits on average, with high variation between participants (**Mean = 2.33, SD = 1.53)**. Users place relatively low importance on financial incentives compared to non-monetary benefits, though the high variability suggests differing individual motivations, indicating that engagement strategies should emphasize both intrinsic and extrinsic factors.

4.6.6 Integration

The OptiWatti demand-response control system scores exceptionally high on operational integration (M = 4.58, SD = 0.38). Participants reported minimal effort required (M = 4.67), high ease of living with the technology (M = 4.67), no negative effect on well-being (M = 4.67), and strong fit with daily energy use (M = 4.33).

4.6.7 Comfort

Users report high comfort with the OptiWatti system (M = 4.83, SD = 0.29), indicating that it integrates well into daily life without disrupting routines or reducing living comfort, suggesting it is well-suited for user-friendly adoption.

4.6.8 Safety Security / Trust

Trust in the OptiWatti system remains moderate (M = 3.62, SD = 0.68). While automated coordination safety (M = 4.00) and device coordination safety (M = 4.00) received positive agreement, lower scores and higher variability emerge around system reliability (M = 3.67), personal data protection (M = 3.50), and prevention of unauthorized device control (M = 3.00). This finding indicates a need for clearer reassurance and communication about how their data is protected.

4.6.9 Additional social challenges, adverse impacts and mitigation

The Finnish questionnaire combines very high comfort (4.83/5) and integration (4.58/5) with a lower trust score (3.62/5). The source interpretation specifically notes uncertainty about data security and unauthorised control. The principal social pathway is therefore not basic usability but confidence in secure, controlled automation while preserving household comfort.

Technical and social evidence address the same heating-service boundary: FCR-D control depends on using building heating flexibility, while the survey indicates that comfort and low effort are important to acceptance. The relationship should be interpreted at pilot level rather than as a quantified causal link between the technical activation logs and the three-person questionnaire.

The Finnish pilot applied several participation safeguards to protect customer comfort, privacy and control. Comfort protection is based on room-level temperature monitoring and predefined flexibility limits. The planned operational principle is that indoor temperature may deviate only within predefined bounds (e.g. maximum ±1 °C from the desired room temperature), ensuring that demand-response actions do not cause excessive comfort degradation.

Customer override functionality is planned through local room-level controls that allow occupants to adjust the target temperature relative to their preferred comfort profile (e.g. −1 °C, nominal setpoint, +1 °C or +2 °C). The same concept can also be implemented through the OptiWatti user interface.

Regarding activation transparency, flexibility activations are already recorded in the measurement database as dedicated demand-response indicators for FCR-D Up and FCR-D Down services. Although the current STREAM implementation does not visualise these activations in the customer interface, future versions could provide graphical indicators or activation-history views showing when and how much flexibility has been activated.

Data security is based on encrypted communications (HTTPS and MQTT/SSL), separation of operational measurement data from customer-identifiable information, restricted database access through application programming interfaces only, VPN-secured communication with Fingrid, and architectural separation between apartment controllers and backend systems. Measurement databases contain only technical identifiers, while personal customer information is stored separately.

No direct financial compensation scheme was implemented for pilot participants. OptiWatti's assessment indicates that both the customer costs and direct financial benefits of reserve-market participation are minimal. Therefore, no customer compensation model has been adopted.

Additional participation safeguards may be implemented through occupancy-aware control constraints. For example, calendar-based information can be used to exclude occupied rooms from demand-response activation, and these restrictions can be considered when calculating the flexibility potential available for market participation.

Residual social risks mainly concern customer awareness of flexibility activations, perceived control over automated operation and trust in data handling, although the pilot incorporates technical, organisational and cybersecurity measures to mitigate these concerns.

4.7 CROSS-PILOT SOCIAL SYNTHESIS AND CONCLUSIONS

Across the four pilot sites, the social assessment shows that user control, transparency, trust, comfort and operational constraints are important factors for participation in flexibility services. The results also show that motivations differ between participant groups and can include both monetary and non-monetary benefits.

Within those boundaries, social and environmental motivations are strong where measured, convenience/integration is generally positive, and trust remains important. The Finnish trust score (3.62/5) is lower than its integration and comfort scores, while Spanish open feedback raises uncertainty about external device control and the Italian household open comment raises a possible EV-battery-lifetime concern. Slovenian industry and Italian water respondents emphasise guarantees, operator control, emergency conditions, cybersecurity and clear responsibility.

Based on the results in this assessment, we can conclude that flexibility services are more acceptable when:

- Participation is understandable,
- Operational control is retained,
- Critical-service or production constraints are protected,
- The value proposition includes both system/social and financial motives where relevant.

5 CONCLUSIONS

This deliverable assessed the technical, environmental and social impacts of the STREAM demonstrations in Slovenia, Spain, Italy and Finland.

From the **technical perspective**, STREAM connected data collection, grid analytics, asset management and market or control processes across different pilot architectures. **Slovenia** demonstrated data collection reliability of 97.9 - 100% and tool communication reliability of 99 - 100%, together with forecasting, planning, registration, prequalification and local-market functions. In **Spain**, voltage deviations were reduced by 30.8%, representing a conservative estimate of the battery's impact, as a larger number of voltage deviations would likely have occurred in the absence of both the battery and the PV generation limitation. Local self-consumption reached 93.6%, indicating that almost all locally generated surplus was used within the community rather than exported to the grid, demonstrating the effectiveness of P2P trading in increasing the local utilisation of renewable generation. Flexibility request coverage was 27.0%, reflecting the limited number of assets participating in the demonstration and their restricted available capacity, as none were fully dedicated to providing flexibility services to the market. Delivery compliance reached 67.2%, meaning that assets delivered more than half of the flexibility committed, suggesting that less flexibility should be offered. In **Italy**, provider onboarding and EV-marketplace activation were demonstrated, while PV-aware water-pump optimisation increased PV electricity used for pumping by 35.2% for the representative day. In **Finland**, residential electric-heating loads were aggregated for FCR-D using real-load and scaled simulated tests. For the real-load tests, activation compliance was 41% for FCR-D-up and 42% for FCR-D-down showing partial success in fulfilling activation requests that lasted the minimum duration mark. Reliable data, suitable grid models, available assets and sufficient portfolio scale were common premises throughout the pilots. Some congestion tests used forced or controlled conditions, so the results may differ from normal grid operation.

From the **environmental perspective**, results depend on the pilot and baseline. In **Slovenia**, modelled flexibility reduced GWP associated with required grid reinforcement by up to 70% in the assessed scenarios, although grid infrastructure represents only a small part of total electricity-system impacts. In **Italy**, PV-aware pumping reduced modelled GWP (expressed as CO_2e) by 28% and non-renewable cumulative energy demand by almost 30% compared with the baseline 24-hour schedule. In **Finland**, FCR-D changed heating electricity consumption by less than 1%. The added control hardware also had a GWP of 0.6–1.3 t CO_2e, compared with 100 t CO_2e for the battery system in the reference case. In **Spain**, the impact was mainly determined by electricity generation. For example, battery production and grid reinforcement contributed only 1–2% of total GWP. The grid-reinforcement case showed the lowest GWP 139 g CO_2e/kWh, compared with 146 g CO_2e/kWh for the battery-based case, while the case without battery or PV had the highest GWP at 180 g CO_2e/kWh.

From the **social perspective**, the participating samples showed generally positive motivation about joining flexibility schemes, integration and comfort, but acceptance remains conditional. Trust, external control, production continuity, emergency operation, cybersecurity, clear responsibilities and the possibility to override activation remain important.

Overall, STREAM demonstrated workable pilot-level pathways for distributed flexibility in grid, market and frequency-response services. This deliverable shows that flexibility can create technical and environmental benefits, while D6.2 highlights also the economic value by reducing or deferring grid investment or enabling revenue from flexibility services. From an environmental perspective, the impacts of electricity supply are generally more significant than those of the physical infrastructure itself. The main environmental effect of flexibility services depends on when electricity is consumed and whether it is supplied by local renewable generation or by the grid. As the analysed cases lead only to limited changes in electricity consumption, the overall environmental impact remains low.

From an economic perspective, revenues can be substantial even when flexibility is activated infrequently, as market prices are the main driver of profitability. The choice between increasing grid capacity or using flexibility is highly grid specific. It depends on local network conditions, electricity flows and price developments, from both an economic and an environmental perspective.

6 REFERENCES AND ABBREVIATIONS

6.1 REFERENCES

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6.2 ABBREVIATIONS

Abbreviation	Meaning
BAU	Business-as-Usual
CED	Cumulative Energy Demand
CEDnr	Non-renewable Cumulative Energy Demand
CEDr	Renewable Cumulative Energy Demand
CEDtot	Total Cumulative Energy Demand
CO_2e	Carbon-Dioxide-Equivalent
DA	Day-Ahead
DER	Distributed Energy Resource
DSO	Distribution System Operator
EnC	Energy Community
EV	Electric Vehicle
FCR-D	Frequency Containment Reserve for Disturbances
GHG	Greenhouse Gases
GISR	Grid Investment Savings Ratio
GWP	Global Warming Potential
HV	High Voltage
HVAC	Heating, Ventilation and Air Conditioning
KPI	Key Performance Indicator
LFM	Local Flexibility Market
LFP	Lithium Iron Phosphate
LV	Low Voltage
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MV	Medium Voltage
PV	Photovoltaic

RMSE	Root Mean Square Error
RoW	Rest of World
RTP	Razdelilna transformatorska postaja *(Slovenian term meaning distribution transformer substation / primary substation)*
ST	Short-Term
TSO	Transmission System Operator
UC	Use Case
WMAPE	Weighted Mean Absolute Percentage Error

ANNEX A - ADDITIONAL INFORMATION AND RESULTS OF THE ENVIRONMENTAL IMPACT ASSESSMENT

6.3 BACKGROUND DATA

The supplied evidence does not include the process-level ecoinvent 3.12 Cutoff dataset list used in the pilot LCAs; therefore, the exact process inventory cannot be reproduced in this annex without the source records. For some processes, a higher data quality could be achieved by supplementing ecoinvent with other data sources. This applies for electricity from photovoltaics and waste, and for the battery production as described in the data sections of the Spanish and Finnish use cases.

6.3.1 Ecoinvent datasets

The following ecoinvent datasets have been processed for modelling the impact assessment:

- electricity production, hydro, pumped storage | electricity, high voltage | Cutoff, U - SI
- electricity production, hydro, run-of-river | electricity, high voltage | Cutoff, U - SI
- electricity production, natural gas, conventional power plant | electricity, high voltage | Cutoff, U - SI
- heat and power co-generation, natural gas, conventional power plant, 100MW electrical | electricity, high voltage | Cutoff, U - SI
- electricity production, nuclear, pressure water reactor | electricity, high voltage | Cutoff, U - SI
- electricity production, oil | electricity, high voltage | Cutoff, U - SI
- heat and power co-generation, oil | electricity, high voltage | Cutoff, U - SI
- electricity production, wind, <1MW turbine, onshore | electricity, high voltage | Cutoff, U - RoW
- electricity production, wind, 1-3MW turbine, onshore | electricity, high voltage | Cutoff, U - RoW
- heat and power co-generation, biogas, gas engine | electricity, high voltage | Cutoff, U - SI
- heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | electricity, high voltage | Cutoff, U - SI
- heat and power co-generation, lignite | electricity, high voltage | Cutoff, U - SI
- market for transmission network, electricity, high voltage direct current aerial line | transmission network, electricity, high voltage direct current aerial line | Cutoff, U - RER
- market for aluminium, primary, ingot | aluminium, primary, ingot | Cutoff, U
- market for copper, cathode | copper, cathode | Cutoff, U
- market for steel, low-alloyed | steel, low-alloyed | Cutoff, U
- market for polyethylene, high density, granulate | polyethylene, high density, granulate | Cutoff, U
- market for polyvinyl chloride, unspecified polymerisation, weighted average | polyvinyl chloride, unspecified polymerisation, weighted average | Cutoff, U
- market for lubricating oil | lubricating oil | Cutoff, U - RER
- market for sand | sand | Cutoff, U
- market for gravel, crushed | gravel, crushed | Cutoff, U - CH

- excavation, skid-steer loader | excavation, skid-steer loader | Cutoff, U - RER
- electricity production, hydro, pumped storage | electricity, high voltage | Cutoff, U - ES
- electricity production, hydro, run-of-river | electricity, high voltage | Cutoff, U - ES
- electricity production, hydro, reservoir, non-alpine region | electricity, high voltage | Cutoff, U - ES
- electricity production, natural gas, conventional power plant | electricity, high voltage | Cutoff, U - ES
- electricity production, natural gas, combined cycle power plant | electricity, high voltage | Cutoff, U - ES
- treatment of blast furnace gas, in power plant | electricity, high voltage | Cutoff, U - ES
- treatment of coal gas, in power plant | electricity, high voltage | Cutoff, U - ES
- electricity production, nuclear, boiling water reactor | electricity, high voltage | Cutoff, U - ES
- electricity production, nuclear, pressure water reactor | electricity, high voltage | Cutoff, U - ES
- electricity production, oil | electricity, high voltage | Cutoff, U - ES
- electricity production, wind, <1MW turbine, onshore | electricity, high voltage | Cutoff, U - ES
- electricity production, wind, 1-3MW turbine, offshore | electricity, high voltage | Cutoff, U - ES
- electricity production, wind, 1-3MW turbine, onshore | electricity, high voltage | Cutoff, U - ES
- electricity production, wind, >3MW turbine, onshore | electricity, high voltage | Cutoff, U - ES
- heat and power co-generation, biogas, gas engine | electricity, high voltage | Cutoff, U - ES
- heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | electricity, high voltage | Cutoff, U - ES
- electricity production, hard coal | electricity, high voltage | Cutoff, U - ES
- electricity production, solar thermal parabolic trough, 50 MW | electricity, high voltage | Cutoff, U - ES
- electricity production, solar tower power plant, 20 MW | electricity, high voltage | Cutoff, U - ES
- electricity production, deep geothermal | electricity, high voltage | Cutoff, U - IT
- electricity production, hydro, reservoir, alpine region | electricity, high voltage | Cutoff, U - IT
- electricity production, natural gas, conventional power plant | electricity, high voltage | Cutoff, U - IT
- electricity production, natural gas, combined cycle power plant | electricity, high voltage | Cutoff, U - IT
- heat and power co-generation, natural gas, conventional power plant, 100MW electrical | electricity, high voltage | Cutoff, U - IT
- heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical | electricity, high voltage | Cutoff, U - IT
- electricity production, oil | electricity, high voltage | Cutoff, U - IT
- heat and power co-generation, oil | electricity, high voltage | Cutoff, U - IT
- electricity production, wind, <1MW turbine, onshore | electricity, high voltage | Cutoff, U - IT

- electricity production, wind, 1-3MW turbine, onshore | electricity, high voltage | Cutoff, U - IT
- electricity production, wind, >3MW turbine, onshore | electricity, high voltage | Cutoff, U - IT
- heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | electricity, high voltage | Cutoff, U - IT
- market for transmission network, electricity, high voltage direct current aerial line | transmission network, electricity, high voltage direct current aerial line | Cutoff, U - RER
- market for transmission network, electricity, high voltage direct current land cable | transmission network, electricity, high voltage direct current land cable | Cutoff, U - RER
- market for transmission network, electricity, high voltage direct current subsea cable | transmission network, electricity, high voltage direct current subsea cable | Cutoff, U - RER
- router, internet | router, internet | Cutoff, U - RoW
- internet access equipment production | internet access equipment | Cutoff, U - RoW
- electronics production, for control units | electronics, for control units | Cutoff, U – RoW

6.3.2 Additional background data

Electricity data has been supplemented by more specific sources, as the following table demonstrates:

Table 76: Additional electricity background data

1 kWh electricity			*total performance*	*GWP*	*CEDnr*	*CEDr*	*CEDtot*
	source	*location*	[kWh/kWp]	[g CO_2-eq]	[kWh]	[kWh]	[kWh]
from PV	[11]	Terni (I)	40966	25.3	0.10	1.02	1.12
from PV	[11]	Ajdovščina (SLO)	38756	26.8	0.11	1.02	1.13
from PV	[11]	Crevillent (E)	50322	20.6	0.08	1.01	1.10
from waste combustion	expert estimation	Europe	-	995.6	5.51	0.00	5.51

6.4 RESULTS OF THE ENVIRONMENTAL IMPACT ASSESSMENT

6.4.1 Slovenian Pilot

The following tables report one-week electricity consumption, GWP and cumulative energy demand (CEDtot total, CEDnr non-renewable, CEDr renewable) for all technical settings and stress levels. PV = photovoltaics; PVBESS = photovoltaics with battery storage; EV+HP = electrification with electric vehicles and heat pumps; EV+HP+PV = electrification with photovoltaics; Combined = electrification with photovoltaics and battery storage.

6.4.1.1 Spring

Table 77: Slovenian spring environmental results — PV-LowStress

1 Week Spring	Electricity	GWP	CEDtot	CEDnr	CEDr
PV-LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	817	234	2145	1838	306
El from PV	117	3	132	13	119
El to Grid	-5	-4	-10	-15	5
Grid	0.00	0.21	0.80	0.78	0.02
Grid + Flex	0.00	0.21	0.80	0.78	0.02
Save by Flex	0%	0%	0%	0%	0%
El total supply	934	237	2277	1851	426

Table 78: Slovenian spring environmental results — PV-Reference

1 Week Spring	Electricity	GWP	CEDtot	CEDnr	CEDr
PV-Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	767	221	2017	1731	286
El from PV	195	5	221	22	200
El to Grid	-14	-9	-26	-41	14
Grid	0.00	0.29	1.14	1.11	0.03
Grid + Flex	0.00	0.29	1.13	1.10	0.02
Save by Flex	0%	1%	1%	1%	8%
El total supply	962	226	2212	1712	500

Table 79: Slovenian spring environmental results — PV-HighStress

1 Week Spring	Electricity	GWP	CEDtot	CEDnr	CEDr
PV-HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	642	186	1698	1462	237

El from PV	354	10	401	39	362
El to Grid	-57	-38	-106	-164	58
Grid	0.00	0.49	1.92	1.87	0.05
Grid + Flex	0.00	0.30	1.17	1.15	0.02
Save by Flex	0%	39%	39%	39%	48%
El total supply	997	196	1994	1337	657

Table 80: Slovenian spring environmental results — PVBESS-LowStress

1 Week Spring	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
PVBESS-LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	818	234	2147	1840	307
El from PV	115	3	135	17	118
El to Grid	-4	-3	-8	-12	4
Grid	0.00	0.21	0.80	0.78	0.02
Grid + Flex	0.00	0.21	0.80	0.78	0.02
Save by Flex	0%	0%	0%	0%	0%
El total supply	933	237	2282	1858	425

Table 81: Slovenian spring environmental results — PVBESS-Reference

1 Week Spring	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
PVBESS-Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	767	220	2017	1730	287
El from PV	194	5	228	29	199
El to Grid	-11	-8	-21	-32	11
Grid	0.00	0.29	1.14	1.11	0.03
Grid + Flex	0.00	0.29	1.13	1.10	0.02
Save by Flex	0%	1%	1%	1%	8%

El total supply	962	226	2244	1759	485

Table 82: Slovenian spring environmental results — PVBESS-HighStress

1 Week Spring	Electricity	GWP	CEDtot	CEDnr	CEDr
PVBESS-HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	640	185	1690	1453	237
El from PV	355	10	416	53	363
El to Grid	-46	-31	-86	-132	47
Grid	0.00	0.49	1.92	1.87	0.05
Grid + Flex	0.00	0.30	1.17	1.15	0.02
Save by Flex	0%	39%	39%	39%	48%
El total supply	995	195	2106	1506	600

Table 83: Slovenian spring environmental results — EV+HP-LowStress

1 Week Spring	Electricity	GWP	CEDtot	CEDnr	CEDr
EV+HP-LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	945	268	2477	2120	357
El from PV	0	0	0	0	0
El to Grid	0	0	0	0	0
Grid	0.00	0.22	0.85	0.83	0.02
Grid + Flex	0.00	0.18	0.69	0.67	0.01
Save by Flex	0%	19%	19%	19%	23%
El total supply	945	268	2477	2120	357

Table 84: Slovenian spring environmental results — EV+HP-Reference

1 Week Spring	Electricity	GWP	CEDtot	CEDnr	CEDr
EV+HP-Reference	MWh	t CO_2e	MWh	MWh	MWh

El from Grid	1011	287	2649	2267	382
El from PV	0	0	0	0	0
El to Grid	0	0	0	0	0
Grid	0.00	0.24	0.94	0.92	0.02
Grid + Flex	0.00	0.19	0.74	0.73	0.02
Save by Flex	0%	21%	21%	21%	22%
El total supply	1011	287	2649	2267	382

Table 85: Slovenian spring environmental results — EV+HP-HighStress

1 Week Spring	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
EV+HP-HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	1115	316	2921	2499	422
El from PV	0	0	0	0	0
El to Grid	0	0	0	0	0
Grid	0.00	0.64	2.48	2.44	0.05
Grid + Flex	0.00	0.18	0.71	0.70	0.01
Save by Flex	0%	71%	71%	71%	72%
El total supply	1115	316	2921	2499	422

Table 86: Slovenian spring environmental results — EV+HP+PV-LowStress

1 Week Spring	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
EV+HP+PV-LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	831	238	2183	1871	312
El from PV	117	3	137	17	120
El to Grid	-5	-3	-9	-14	5
Grid	0.00	0.21	0.80	0.78	0.02
Grid + Flex	0.00	0.16	0.64	0.63	0.01

Save by Flex	0%	20%	20%	20%	26%
El total supply	949	241	2320	1889	432

Table 87: Slovenian spring environmental results — EV+HP+PV-Reference

1 Week Spring	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
EV+HP+PV-Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	819	235	2153	1846	306
El from PV	197	5	231	29	201
El to Grid	-12	-8	-23	-36	13
Grid	0.00	0.30	1.16	1.13	0.03
Grid + Flex	0.00	0.23	0.90	0.88	0.02
Save by Flex	0%	22%	22%	22%	34%
El total supply	1016	240	2384	1876	508

Table 88: Slovenian spring environmental results — EV+HP+PV-HighStress

1 Week Spring	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
EV+HP+PV-HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	760	219	2007	1725	282
El from PV	364	10	426	54	372
El to Grid	-48	-32	-88	-136	48
Grid	0.00	0.65	2.54	2.49	0.05
Grid + Flex	0.00	0.25	0.99	0.97	0.02
Save by Flex	*0%*	*61%*	*61%*	*61%*	*64%*
El total supply	*1124*	*229*	*2434*	*1779*	*655*

Table 89: Slovenian spring environmental results — Combined - LowStress

1 Week Spring	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*

Combined - LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	833	238	2186	1873	313
El from PV	115	3	135	17	118
El to Grid	-4	-3	-7	-12	4
Grid	0.00	0.21	0.80	0.78	0.02
Grid + Flex	0.00	0.16	0.64	0.63	0.01
Save by Flex	0%	20%	20%	20%	26%
El total supply	948	241	2321	1890	431

Table 90: Slovenian spring environmental results — Combined - Reference

1 Week Spring	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
Combined - Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	819	235	2153	1846	307
El from PV	196	5	229	29	200
El to Grid	-10	-7	-19	-29	10
Grid	0.00	0.29	1.14	1.11	0.03
Grid + Flex	0.00	0.23	0.90	0.88	0.02
Save by Flex	0%	21%	21%	21%	34%
El total supply	1015	240	2382	1875	507

Table 91: Slovenian spring environmental results — Combined - HighStress

1 Week Spring	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
Combined - HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	760	219	2004	1721	283
El from PV	363	10	425	54	371
El to Grid	-39	-26	-72	-112	39
Grid	0.00	0.54	2.09	2.04	0.05

Grid + Flex	0.00	0.25	0.98	0.97	0.02
Save by Flex	*0%*	*53%*	*53%*	*53%*	*57%*
El total supply	*1123*	*228*	*2429*	*1775*	*654*

6.4.1.2 Summer

Table 92: Slovenian summer environmental results — PV-LowStress

1 Week Summer	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
PV-LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	920	191	2175	1709	466
El from PV	130	4	147	14	133
El to Grid	-3	-2	-5	-7	3
Grid	0.00	0.26	1.02	0.99	0.02
Grid + Flex	0.00	0.26	1.01	0.99	0.02
Save by Flex	0%	0%	0%	0%	0%
El total supply	1050	194	2322	1724	598

Table 93: Slovenian summer environmental results — PV-Reference

1 Week Summer	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
PV-Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	866	182	2054	1618	436
El from PV	217	6	245	24	221
El to Grid	-11	-7	-20	-31	11
Grid	0.00	0.28	1.10	1.07	0.03
Grid + Flex	0.00	0.28	1.09	1.07	0.03
Save by Flex	0%	0%	0%	0%	0%
El total supply	1083	188	2279	1611	668

Table 94: Slovenian summer environmental results — PV-HighStress

1 Week Summer	Electricity	GWP	CEDtot	CEDnr	CEDr
PV-HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	724	158	1734	1377	357
El from PV	396	11	448	44	405
El to Grid	-51	-34	-95	-146	51
Grid	0.00	0.52	2.02	1.97	0.05
Grid + Flex	0.00	0.28	1.08	1.05	0.03
Save by Flex	0%	47%	47%	47%	48%
El total supply	1120	169	2088	1275	813

Table 95: Slovenian summer environmental results — PVBESS-LowStress

1 Week Summer	Electricity	GWP	CEDtot	CEDnr	CEDr
PVBESS-LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	922	191	2177	1710	467
El from PV	128	3	150	19	131
El to Grid	-2	-1	-4	-6	2
Grid	0.00	0.26	1.02	0.99	0.02
Grid + Flex	0.00	0.26	1.01	0.99	0.02
Save by Flex	0%	0%	0%	0%	0%
El total supply	1050	194	2327	1729	598

Table 96: Slovenian summer environmental results — PVBESS-Reference

1 Week Summer	Electricity	GWP	CEDtot	CEDnr	CEDr
PVBESS-Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	868	182	2057	1619	438
El from PV	214	6	250	32	219

El to Grid	-9	-6	-16	-25	9
Grid	0.00	0.30	1.17	1.14	0.03
Grid + Flex	0.00	0.30	1.17	1.14	0.03
Save by Flex	0%	0%	0%	0%	0%
El total supply	1082	188	2307	1651	656

Table 97: Slovenian summer environmental results — PVBESS-HighStress

1 Week Summer	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
PVBESS-HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	724	156	1731	1372	359
El from PV	395	11	462	59	404
El to Grid	-42	-28	-78	-120	42
Grid	0.00	0.54	2.11	2.06	0.05
Grid + Flex	0.00	0.28	1.08	1.05	0.03
Save by Flex	0%	49%	49%	49%	50%
El total supply	1119	167	2193	1431	762

Table 98: Slovenian summer environmental results — EV+HP-LowStress

1 Week Summer	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
EV+HP-LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	1060	216	2498	1959	540
El from PV	0	0	0	0	0
El to Grid	0	0	0	0	0
Grid	0.00	0.28	1.11	1.08	0.02
Grid + Flex	0.00	0.24	0.95	0.93	0.02
Save by Flex	0%	14%	14%	14%	19%
El total supply	1060	216	2498	1959	540

Table 99: Slovenian summer environmental results — EV+HP-Reference

1 Week Summer	Electricity	GWP	CEDtot	CEDnr	CEDr
EV+HP-Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	1126	230	2654	2082	573
El from PV	0	0	0	0	0
El to Grid	0	0	0	0	0
Grid	0.00	0.31	1.19	1.17	0.02
Grid + Flex	0.00	0.26	0.99	0.97	0.02
Save by Flex	0%	17%	17%	17%	15%
El total supply	1126	230	2654	2082	573

Table 100: Slovenian summer environmental results — EV+HP-HighStress

1 Week Summer	Electricity	GWP	CEDtot	CEDnr	CEDr
EV+HP-HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	1226	251	2891	2268	623
El from PV	0	0	0	0	0
El to Grid	0	0	0	0	0
Grid	0.00	0.66	2.56	2.51	0.05
Grid + Flex	0.00	0.25	0.95	0.93	0.02
Save by Flex	0%	63%	63%	63%	60%
El total supply	1226	251	2891	2268	623

Table 101: Slovenian summer environmental results — EV+HP+PV-LowStress

1 Week Summer	Electricity	GWP	CEDtot	CEDnr	CEDr
EV+HP+PV-LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	934	194	2207	1735	472

El from PV	130	4	152	19	133
El to Grid	-2	-2	-4	-7	2
Grid	0.00	0.26	1.02	0.99	0.02
Grid + Flex	0.00	0.23	0.90	0.88	0.02
Save by Flex	0%	12%	12%	12%	18%
El total supply	1064	197	2360	1754	605

Table 102: Slovenian summer environmental results — EV+HP+PV-Reference

1 Week Summer	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
EV+HP+PV-Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	914	193	2167	1708	460
El from PV	218	6	255	32	223
El to Grid	-10	-6	-18	-27	10
Grid	0.00	0.30	1.17	1.14	0.03
Grid + Flex	0.00	0.25	0.98	0.96	0.02
Save by Flex	0%	16%	16%	16%	19%
El total supply	1132	199	2422	1740	682

Table 103: Slovenian summer environmental results — EV+HP+PV-HighStress

1 Week Summer	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
EV+HP+PV-HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	832	182	1991	1580	411
El from PV	404	11	472	60	412
El to Grid	-43	-29	-81	-124	44
Grid	0.00	0.59	2.29	2.24	0.05
Grid + Flex	0.00	0.28	1.07	1.05	0.02
Save by Flex	0%	53%	53%	53%	52%

El total supply	1236	193	2464	1640	824

Table 104: Slovenian summer environmental results — Combined - LowStress

1 Week Summer	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
Combined - LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	935	194	2210	1736	474
El from PV	128	3	150	19	131
El to Grid	-2	-1	-3	-5	2
Grid	0.00	0.28	1.09	1.06	0.02
Grid + Flex	0.00	0.23	0.90	0.88	0.02
Save by Flex	*0%*	*17%*	*18%*	*17%*	*26%*
El total supply	*1064*	*197*	*2360*	*1755*	*605*

Table 105: Slovenian summer environmental results — Combined - Reference

1 Week Summer	Electricity	GWP	CEDtot	CEDnr	CEDr
Combined - Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	916	192	2171	1710	461
El from PV	215	6	252	32	220
El to Grid	-8	-5	-15	-23	8
Grid	0.00	0.30	1.17	1.14	0.03
Grid + Flex	0.00	0.25	0.98	0.96	0.02
Save by Flex	*0%*	*16%*	*16%*	*16%*	*19%*
El total supply	*1131*	*198*	*2423*	*1742*	*681*

Table 106: Slovenian summer environmental results — Combined - HighStress

1 Week Summer	Electricity	GWP	CEDtot	CEDnr	CEDr
Combined - HighStress	MWh	t CO_2e	MWh	MWh	MWh

El from Grid	834	180	1990	1577	414
El from PV	401	11	470	60	410
El to Grid	-36	-24	-66	-103	36
Grid	0.00	0.51	1.99	1.94	0.05
Grid + Flex	0.00	0.28	1.07	1.05	0.02
Save by Flex	*0%*	*46%*	*46%*	*46%*	*49%*
El total supply	*1235*	*191*	*2460*	*1637*	*823*

6.4.1.3 Autumn

Table 107: Slovenian autumn environmental results — PV-LowStress

1 Week Autumn	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
PV-LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	898	269	2550	2279	271
El from PV	106	3	120	12	108
El to Grid	0	0	-1	-1	0
Grid	0.00	0.24	0.94	0.92	0.02
Grid + Flex	0.00	0.24	0.94	0.92	0.02
Save by Flex	0%	0%	0%	0%	4%
El total supply	1004	272	2670	2291	380

Table 108: Slovenian autumn environmental results — PV-Reference

1 Week Autumn	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
PV-Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	858	260	2436	2179	257
El from PV	175	5	198	19	178
El to Grid	-8	-5	-15	-23	8
Grid	0.00	0.25	0.98	0.95	0.02

Grid + Flex	0.00	0.24	0.92	0.90	0.02
Save by Flex	0%	6%	6%	6%	11%
El total supply	1032	264	2619	2175	444

Table 109: Slovenian autumn environmental results — PV-HighStress

1 Week Autumn	Electricity	GWP	CEDtot	CEDnr	CEDr
PV-HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	751	232	2131	1909	222
El from PV	316	8	357	35	322
El to Grid	-43	-29	-80	-124	44
Grid	0.00	0.42	1.66	1.61	0.04
Grid + Flex	0.00	0.28	1.08	1.05	0.02
Save by Flex	0%	35%	35%	35%	42%
El total supply	1066	240	2408	1820	588

Table 110: Slovenian autumn environmental results — PVBESS-LowStress

1 Week Autumn	Electricity	GWP	CEDtot	CEDnr	CEDr
PVBESS-LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	899	269	2557	2285	272
El from PV	104	3	121	15	106
El to Grid	0	0	-1	-1	0
Grid	0.00	0.24	0.94	0.92	0.02
Grid + Flex	0.00	0.24	0.94	0.92	0.02
Save by Flex	0%	0%	0%	0%	4%
El total supply	1003	272	2679	2301	378

Table 111: Slovenian autumn environmental results — PVBESS-Reference

1 Week Autumn	Electricity	GWP	CEDtot	CEDnr	CEDr
PVBESS-Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	859	259	2440	2182	258
El from PV	173	5	202	26	176
El to Grid	-6	-4	-11	-17	6
Grid	0.00	0.25	0.98	0.95	0.02
Grid + Flex	0.00	0.24	0.92	0.90	0.02
Save by Flex	0%	6%	6%	5%	11%
El total supply	1032	264	2642	2208	435

Table 112: Slovenian autumn environmental results — PVBESS-HighStress

1 Week Autumn	Electricity	GWP	CEDtot	CEDnr	CEDr
PVBESS-HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	749	230	2126	1904	222
El from PV	316	9	370	47	323
El to Grid	-34	-23	-62	-96	34
Grid	0.00	0.41	1.58	1.54	0.04
Grid + Flex	0.00	0.28	1.08	1.05	0.02
Save by Flex	0%	32%	32%	32%	39%
El total supply	1065	238	2496	1951	545

Table 113: Slovenian autumn environmental results — EV+HP-Reference

1 Week Autumn	Electricity	GWP	CEDtot	CEDnr	CEDr
EV+HP-Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	1082	320	3071	2740	331
El from PV	0	0	0	0	0

El to Grid	0	0	0	0	0
Grid	0.00	0.26	1.00	0.98	0.02
Grid + Flex	0.00	0.18	0.69	0.68	0.01
Save by Flex	0%	31%	31%	31%	37%
El total supply	1082	320	3071	2740	331

Table 114: Slovenian autumn environmental results — EV+HP-HighStress

1 Week Autumn	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
EV+HP-HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	1185	351	3359	2995	364
El from PV	0	0	0	0	0
El to Grid	0	0	0	0	0
Grid	0.00	0.68	2.63	2.58	0.05
Grid + Flex	0.00	0.20	0.78	0.76	0.01
Save by Flex	0%	70%	70%	70%	70%
El total supply	1185	351	3359	2995	364

Table 115: Slovenian autumn environmental results — EV+HP+PV-LowStress

1 Week Autumn	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
EV+HP+PV-LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	912	274	2591	2314	276
El from PV	106	3	124	16	108
El to Grid	0	0	-1	-1	0
Grid	0.00	0.24	0.94	0.92	0.02
Grid + Flex	0.00	0.19	0.75	0.73	0.02
Save by Flex	0%	20%	20%	20%	28%
El total supply	1018	277	2715	2330	385

Table 116: Slovenian autumn environmental results — EV+HP+PV-Reference

1 Week Autumn	Electricity	GWP	CEDtot	CEDnr	CEDr
EV+HP+PV-Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	909	275	2577	2303	274
El from PV	176	5	206	26	180
El to Grid	-6	-4	-12	-18	6
Grid	0.00	0.26	1.02	0.99	0.03
Grid + Flex	0.00	0.16	0.62	0.60	0.01
Save by Flex	0%	39%	40%	39%	49%
El total supply	1085	280	2784	2329	455

Table 117: Slovenian autumn environmental results — EV+HP+PV-HighStress

1 Week Autumn	Electricity	GWP	CEDtot	CEDnr	CEDr
EV+HP+PV-HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	870	268	2461	2200	261
El from PV	322	9	377	48	329
El to Grid	-37	-25	-69	-106	37
Grid	0.00	0.59	2.28	2.23	0.05
Grid + Flex	0.00	0.22	0.84	0.82	0.02
Save by Flex	0%	63%	63%	63%	65%
El total supply	1192	277	2838	2248	590

Table 118: Slovenian autumn environmental results — Combined - LowStress

1 Week Autumn	Electricity	GWP	CEDtot	CEDnr	CEDr
Combined - LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	914	274	2597	2321	277

El from PV	104	3	122	15	106
El to Grid	0	0	-1	-1	0
Grid	0.00	0.24	0.94	0.92	0.02
Grid + Flex	0.00	0.19	0.75	0.73	0.02
Save by Flex	0%	20%	20%	20%	28%
El total supply	1018	277	2719	2336	383

Table 119: Slovenian autumn environmental results — Combined - Reference

1 Week Autumn	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
Combined - Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	911	275	2582	2307	275
El from PV	174	5	204	26	178
El to Grid	-5	-3	-9	-13	5
Grid	0.00	0.26	1.00	0.97	0.02
Grid + Flex	0.00	0.16	0.62	0.60	0.01
Save by Flex	0%	38%	38%	38%	49%
El total supply	1084	280	2786	2333	453

Table 120: Slovenian autumn environmental results — Combined - HighStress

1 Week Autumn	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
Combined - HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	870	266	2460	2198	262
El from PV	321	9	375	48	328
El to Grid	-29	-19	-54	-83	29
Grid	0.00	0.47	1.83	1.79	0.04
Grid + Flex	0.00	0.22	0.84	0.82	0.02
Save by Flex	0%	54%	54%	54%	58%

El total supply	1190	275	2835	2246	590

6.4.1.4 Winter

Table 121: Slovenian winter environmental results — PV-LowStress

1 Week Winter	Electricity	GWP	CEDtot	CEDnr	CEDr
PV-LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	868	335	2460	2232	228
El from PV	89	2	101	10	91
El to Grid	0	0	0	0	0
Grid	0.00	0.30	1.16	1.14	0.02
Grid + Flex	0.00	0.29	1.12	1.09	0.02
Save by Flex	0%	4%	4%	4%	6%
El total supply	957	337	2561	2241	320

Table 122: Slovenian winter environmental results — PV-Reference

1 Week Winter	Electricity	GWP	CEDtot	CEDnr	CEDr
PV-Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	833	322	2366	2148	218
El from PV	152	4	172	17	155
El to Grid	-1	-1	-3	-4	1
Grid	0.00	0.32	1.24	1.21	0.03
Grid + Flex	0.00	0.32	1.23	1.21	0.03
Save by Flex	0%	0%	0%	0%	3%
El total supply	985	326	2535	2161	374

Table 123: Slovenian winter environmental results — PV-HighStress

1 Week Winter	Electricity	GWP	CEDtot	CEDnr	CEDr
PV-HighStress	MWh	t CO_2e	MWh	MWh	MWh

El from Grid	740	286	2112	1924	188
El from PV	276	7	312	30	282
El to Grid	-25	-17	-47	-73	26
Grid	0.00	0.43	1.66	1.62	0.04
Grid + Flex	0.00	0.39	1.51	1.48	0.03
Save by Flex	0%	9%	9%	9%	13%
El total supply	1016	293	2378	1882	496

Table 124: Slovenian winter environmental results — PVBESS-LowStress

1 Week Winter	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
PVBESS-LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	869	335	2464	2235	229
El from PV	87	2	102	13	89
El to Grid	0	0	0	0	0
Grid	0.00	0.29	1.12	1.09	0.02
Grid + Flex	0.00	0.29	1.12	1.09	0.02
Save by Flex	0%	0%	0%	0%	0%
El total supply	957	337	2566	2248	319

Table 125: Slovenian winter environmental results — PVBESS-Reference

1 Week Winter	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
PVBESS-Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	836	322	2371	2151	219
El from PV	149	4	174	22	152
El to Grid	-1	0	-1	-2	1
Grid	0.00	0.31	1.22	1.19	0.03
Grid + Flex	0.00	0.31	1.21	1.19	0.03

Save by Flex	0%	0%	0%	0%	3%
El total supply	984	326	2545	2174	371

Table 126: Slovenian winter environmental results — PVBESS-HighStress

1 Week Winter	Electricity	GWP	CEDtot	CEDnr	CEDr
PVBESS-HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	737	284	2097	1907	190
El from PV	277	7	324	41	283
El to Grid	-16	-11	-30	-46	16
Grid	0.00	0.41	1.59	1.55	0.04
Grid + Flex	0.00	0.37	1.44	1.41	0.03
Save by Flex	0%	9%	9%	9%	14%
El total supply	1014	291	2422	1948	473

Table 127: Slovenian winter environmental results — EV+HP-Reference

1 Week Winter	Electricity	GWP	CEDtot	CEDnr	CEDr
EV+HP-Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	1045	402	2954	2675	279
El from PV	0	0	0	0	0
El to Grid	0	0	0	0	0
Grid	0.00	0.43	1.67	1.63	0.03
Grid + Flex	0.00	0.16	0.61	0.60	0.01
Save by Flex	0%	63%	63%	63%	61%
El total supply	1045	402	2954	2675	279

Table 128: Slovenian winter environmental results — EV+HP-HighStress

1 Week Winter	Electricity	GWP	CEDtot	CEDnr	CEDr

EV+HP-HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	1163	447	3284	2972	311
El from PV	0	0	0	0	0
El to Grid	0	0	0	0	0
Grid	0.00	0.92	3.58	3.52	0.06
Grid + Flex	0.00	0.38	1.49	1.46	0.03
Save by Flex	*0%*	*59%*	*58%*	*59%*	*53%*
El total supply	*1163*	*447*	*3284*	*2972*	*311*

Table 129: Slovenian winter environmental results — EV+HP+PV-LowStress

1 Week Winter	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
EV+HP+PV-LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	885	341	2508	2275	233
El from PV	89	2	105	13	91
El to Grid	0	0	0	0	0
Grid	0.00	0.32	1.23	1.21	0.03
Grid + Flex	0.00	0.14	0.55	0.54	0.01
Save by Flex	0%	56%	56%	56%	56%
El total supply	975	344	2613	2288	325

Table 130: Slovenian winter environmental results — EV+HP+PV-Reference

1 Week Winter	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
EV+HP+PV-Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	896	345	2539	2304	235
El from PV	152	4	178	23	156
El to Grid	-1	-1	-2	-2	1
Grid	0.00	0.39	1.51	1.48	0.03

Grid + Flex	0.00	0.17	0.65	0.63	0.01
Save by Flex	0%	57%	57%	57%	55%
El total supply	1048	349	2717	2327	391

Table 131: Slovenian winter environmental results — EV+HP+PV-HighStress

1 Week Winter	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
EV+HP+PV-HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	887	342	2523	2293	230
El from PV	282	8	330	42	288
El to Grid	-20	-13	-36	-56	20
Grid	0.00	0.87	3.39	3.32	0.06
Grid + Flex	0.00	0.31	1.21	1.19	0.02
Save by Flex	0%	64%	64%	64%	62%
El total supply	1169	349	2852	2335	517

Table 132: Slovenian winter environmental results — Combined - LowStress

1 Week Winter	*Electricity*	*GWP*	*CEDtot*	*CEDnr*	*CEDr*
Combined - LowStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	887	342	2512	2278	234
El from PV	87	2	102	13	89
El to Grid	0	0	0	0	0
Grid	0.00	0.29	1.14	1.11	0.02
Grid + Flex	0.00	0.14	0.55	0.54	0.01
Save by Flex	0%	52%	52%	52%	50%
El total supply	974	344	2614	2291	324

Table 133: Slovenian winter environmental results — Combined - Reference

1 Week Winter	Electricity	GWP	CEDtot	CEDnr	CEDr
Combined - Reference	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	898	346	2544	2307	237
El from PV	149	4	174	22	152
El to Grid	0	0	-1	-1	0
Grid	0.00	0.34	1.32	1.29	0.03
Grid + Flex	0.00	0.17	0.65	0.63	0.01
Save by Flex	0%	51%	51%	51%	47%
El total supply	1047	350	2718	2329	389

Table 134: Slovenian winter environmental results — Combined - HighStress

1 Week Winter	Electricity	GWP	CEDtot	CEDnr	CEDr
Combined - HighStress	MWh	t CO_2e	MWh	MWh	MWh
El from Grid	885	340	2512	2280	232
El from PV	281	8	329	42	287
El to Grid	-12	-8	-23	-36	13
Grid	0.00	0.68	2.63	2.57	0.05
Grid + Flex	0.00	0.21	0.82	0.81	0.02
Save by Flex	0%	69%	69%	69%	67%
El total supply	1166	348	2840	2322	519

6.4.2 Spanish Pilot

The following two tables report the global warming potential and the cumulative energy demand of the pilot site for 2025 with a yearly electricity consumption of 453 kWh. Impacts of operation and infrastructure (Battery Production/Grid Reinforcement) are shown separately.

Table 135: Spanish pilot GWP by LCA case

GWP [t CO_2e]	Operation	Battery Production/Grid Reinforcement	Total

Case 1: battery	64.9	1.1	66.0
Case 2: w/o battery; no PV	81.4	0.0	81.4
Case 3: w/o battery; PV partly used	71.9	0.0	71.9
Case 4: grid reinforcement	62.6	0.5	63.1

Table 136: Spanish pilot total CED by LCA case

CED total [MWh]	Operation	Battery Production/Grid Reinforcement	Total
Case 1: battery	852	4.7	857
Case 2: w/o battery; no PV	952	0.0	952
Case 3: w/o battery; PV partly used	886	0.0	886
Case 4: grid reinforcement	843	2.4	844

The four cases require different shares of renewable and non-renewable energy. Both are presented as absolute and relative values.

Table 137: Spanish pilot CEDtot, CEDnr, CEDr by LCA case

	CEDnr		CEDr		CEDtot
	[MWh]		[MWh]		[MWh]
Case 1: battery	224	(26.1%)	634	(74.0%)	857
Case 2: w/o battery; no PV	291	(30.6%)	662	(69.5%)	952
Case 3: w/o battery; PV partly used	244	(27.5%)	643	(72.6%)	886
Case 4: grid reinforcement	198	(23.5%)	648	(76.6%)	845

The following table presents the impacts normalised on one kWh of electricity and compared with impacts of the average Spanish production mix.

Table 138: Spanish pilot relative environmental impacts

	GWP	CEDtot	CEDnr	CEDr
	[g CO_2e/kWh]	[kWh/kWh]	[kWh/kWh]	[kWh/kWh]
Case 1: battery	146	1.89	0.49	1.40
Case 2: w/o battery; no PV	180	2.10	0.64	1.46

Case 3: w/o battery; PV partly used	159	1.95	0.54	1.42
Case 4: grid reinforcement	139	1.86	0.44	1.43
Average production mix	177	2.04	0.61	1.43

6.4.3 Italian Pilot

The following table reports the global warming potential (GWP) and the cumulative energy demand (CEDnr – non-renewable, CEDr – renewable) of the four water pump optimization cases for one day of operation and for four EV charging optimization cases. The relative share of renewable and non-renewable energy demand is shown as percent values.

Table 139: Italian water-pump environmental impacts by operation mode

Pump operation mode	*GWP*	*CEDnr*		*CEDr*		*CEDtot*	
	[kg CO_2e/day]	[MWh/day]		[MWh/day]		[MWh/day]	
Baseline	1,012	4.2	(55%)	3.5	(45%)	7.7	(100%)
PV optimized	715	3.0	(43%)	3.9	(57%)	6.9	(100%)
Cost optimized	874	3.6	(50%)	3.7	(50%)	7.3	(100%)
Congestion optimized	846	3.5	(51%)	3.4	(49%)	6.9	(100%)

The global warming results are calculated additionally normalised on one kWh electricity and compared with the Italian national production mix. They result in the following values:

Table 140: Italian water-pump GWP per kWh electricity consumed

Pump operation mode	*GWP*
	[g CO_2e/kWh]
Baseline	222
PV optimized	155
Cost optimized	192
Congestion optimized	200
Production mix Italy May 2026	*403*

Table 141: Italian EV charging environmental impacts

EV charging mode	*GWP*	*CEDnr*	*CEDr*	*CEDtot*
	[kg CO_2e/day]	[MWh/day]	[MWh/day]	[MWh/day]

Baseline	13	55	(28%)	141	(72%)	195	(100%)
PV optimized	8	32	(16%)	148	(76%)	180	(100%)
Cost optimized	31	128	(66%)	120	(61%)	248	(100%)
Congestion optimized	18	72	(37%)	72	(37%)	208	(100%)

Table 142: Italian EV charging GWP per kWh electricity consumed

EV charging mode	*GWP*
	[g CO_2e/kWh]
Baseline	89
PV optimized	53
Cost optimized	206
Congestion optimized	117
Production mix Italy May 2026	*403*

6.4.4 Finnish Pilot

The following table reports the electricity consumption for heating at the pilot scale (10 apartments) when providing FCR-D services and the respective impacts for global warming potential (GWP) and the cumulative energy demand (CEDnr – non-renewable, CEDr – renewable).

Table 143: Finnish pilot heating and FCR-D environmental impacts

		GWP	CEDnr	CEDr	CEDt
	[kWh/a]	[kg CO2eq]	[kWh]	[kWh]	[kWh]
heating	51,343	7.99	96,185	34,495	130,680
heating incl. FCR-D up	51,278	7.98	96,063	34,451	130,514
heating incl. FCR-D down	52,050	8.10	97,509	34,969	132,478