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Socio-Economic Assessment

Flexibility services based on Connected and Interoperable Hybrid Energy Storage

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Glossary

Abbreviation	**Description**
AAS	Asset Administration Shell
ABAC	Attribute Based Access Control
AC	Air Conditioning
ADMS	Advanced Distribution Management Systems
A.G.G.	Aggregator
A.M.I.	Advanced Metering Infrastructure
AMQP	Advanced Message Queuing Protocol
BESS	Battery Energy Storage System
B.R.P.	Balancing Responsible Party
B.S.P.	Balancing Service Provider
CAPEX	Capital Expenditure
CCGT	Combined Cycle Gas Turbine
CHESS	Connected Hybrid Energy Storage System
C.H.P.	Combined Heat and Power
Container Registry	A place for developers to publish (push) Docker containers to be subsequently retrieved (pulled) for deployment. Container registries contain Container repositories defined by URI syntax including version tags. Credentials are optionally required for access to container registries.
C.P.S.	Cyber-Physical System
CS	Charge Station
DBMS	Database Management Systems
D.E.R.	Distributed Energy Resource
DERMS	Distributed Energy Resource Management System
DF	Distributed Flexibility
DG	Distributed Generation
DHW	Domestic Hot Water

Abbreviation	**Description**
D.L.T.	Distributed Ledger Technology
D.N.O.	Distribution Network Operator
Docker	A set of platforms as a service products that uses OS-level virtualisation to deliver software in packages called containers
Docker Containers	Isolated bundles of software, libraries and configuration files; that can communicate with each other through well-defined channels. Containers are run by a single operating system kernel and therefore use fewer resources than virtual machines
DR.	Demand Response
DRES	Distributed Renewable Energy Source
D.S.M.	Dispatching Service Market
D.S.O.	Distribution System Operator
DT.	Digital Twin
DTDL	Digital Twin Definition Language
DTI	Digital Twin Instance
DTP	Digital Twin Prototype
EC.	Energy Community
E.C.M.	Energy Community Manager
EDC	Eclipse Dataspace Connector
EMSP	Electric Mobility Service Provider
E.S.B.	Enterprise Service Bus
ESCo	Energy Service Company
E.S.O.	Energy System Operator
E.S.S.	Energy Storage System
EV.	Electric Vehicle
FlexCHESS	Flexibility services based on Connected and interoperable HESS
FLEXIS	Flexible Integrated Energy Systems

Abbreviation	Description
FLEX_SP	FlexCHESS Smart Plug / pilot participant identification code
FME	Flexibility Market Emulator
F.S.P.	Flexibility Service Provider
HESS	Hybrid Energy Storage System
HP	Heat Pump
HPAC	Combined Heat Pump / Air Conditioning unit
HVAC	Heating, Ventilation, and Air Conditioning
I.C.T.	Information and Communication Technology
ID	Identifier (digital/device ID)
IDC	IDS Connector
IDS	International Dataspace
IDSA	International Dataspace Association
IDTA	Industrial Digital Twin Association
IP	Internet Protocol (device network address)
KERs	Key Exploitable Results
KPI	Key Performance Indicator
kWh	Kilowatt-hour
MDC	Metering Data Company
MkaaS	Marketplace-as-a-Service
MOM	Message Oriented Middleware
MQTT	Message Queuing Telemetry Transport
NPRS	Non-Programmable Renewable Sources
OPEX	Operational Expenditure
P.L.A.	Production and Load Aggregator
PLSA	Production, Load and Storage Aggregators
PRO	Producer
PRS	Prosumer

Abbreviation	**Description**
P&S	Publish & Subscribe
PV.	Photovoltaics
PV	Photovoltaic (plant/generation asset)
RDBMS	Relational DataBase Management System
REC	Renewable Energy Community
RES	Renewable Energy Source
SAREF	Smart Application Reference
SCADA	Supervisory control and data acquisition
SOC	State of Charge
SP	Smart Plug (metering/monitoring device)
SUP	Supplier
TC	Total Consumption
TNO	Transmission Network Operator
TOU	Time Of Use
TSO	Transmission System Operator
UC	Use Case
UI.	User Interface
UUDEX	Universal Utility Data Exchange
UX	User Experience
V2G	Vehicle To Grid
VESS	Virtual Energy Storage System
VPC	Virtual Private Cloud
VSoC	Virtual State of Charge estimator
V.P.P.	Virtual Power Plant
WHP	Air-to-Water Heat Pump

M26 (January 2025) - M36 (June 2026)

1 Executive Summary

The assessment contributes to the wider WP4 Demonstration and Validation framework by examining the value of FlexCHESS beyond technical performance, with particular attention to social acceptance, perceived benefits and barriers, economic viability, environmental relevance, user/stakeholder engagement, replicability and policy significance.

FlexCHESS develops flexibility services through the aggregation of multiple Connected Hybrid Energy Storage Systems (CHESS) operating collaboratively within CHESS Nodes. The project enables production and consumption units to interact dynamically, adjusting generation, consumption or storage behaviour in response to flexibility needs. This approach supports the integration of distributed energy resources (DERs), enhances the value of flexible assets, and provides a basis for improved grid management, energy optimisation and future flexibility-market participation. Research and work conducted under WP4 demonstrates how the pilot work focused on identifying the most effective DER combinations, defining best practices for integration and operation, and establishing the key requirements for efficient deployment of FlexCHESS Nodes at demonstration sites.

The assessment covers five European pilot contexts: Wales/UK, Slovenia, Spain, Italy and Turkey. These pilots represent different technical, institutional and social environments, including industrial flexibility simulation, DSO-oriented flexibility, renewable energy communities, multi-building energy optimisation, EV smart charging and island-grid resilience. Four FlexCHESS use cases, divided into eight operational scenarios, provide the common assessment framework: UC1 Demand Response for Grid Resilience, UC2 Dynamic Energy Response for Grid Stability, UC3 Virtual Power Plants and Renewable Energy Communities, and UC4 Adaptive Energy Management, including commercial-building optimisation and EV smart charging.

WP4 further records the readiness, assessment relevance and technical basis of the pilot demonstrations. Within this work package, the DER assets, accessible historical or real-time data, controllable parameters, FlexPlatform tools and implementation strategies for each pilot are documented. WP4 also identifies technical deployment requirements for the scenarios, including response time, minimum available power and minimum service duration. These provide the operational basis for assessing flexibility availability, response capacity, asset integration and socio-economic and environmental impact pathways.

The pilots demonstrate different pathways for socio-economic and environmental value creation, based on the systems used in each of them. The Spanish pilot is particularly relevant for renewable energy community participation, PV self-consumption, batteries, flexible household assets and local energy engagement. The Italian pilot presents a strong multi-building optimisation case, combining PV, EV charging, battery storage and HVAC/refrigeration assets, with high feasibility identified for peak shaving, load shifting and commercial-building energy optimisation. The Slovenian pilot addresses close-to-real-time DSO flexibility through distributed generators, PV, aggregated EV flexibility, behind-the-meter DERs and prosumer participation, with a clear focus on flexibility provision for DSO needs. The Turkish pilot addresses the specific challenges of an island energy community, including wind and PV generation, battery storage, heat pump, EV assets, smart meters, submarine cable dependency, renewable variability and frequency-stability needs. And, lastly, the Welsh pilot contributes simulation-based evidence from a complex industrial and energy-system context in Wales, including generation, storage, industrial loads and VESS-related modelling.

The assessment combines Social Life Cycle Assessment (S-LCA)-informed thinking, life cycle cost analysis (LCCA), ex-ante environmental assessment, stakeholder engagement evidence, pilot-readiness review and cross-pilot comparison. It focuses on both measurable and qualitative impact pathways: stakeholder acceptance, trust and perceived usefulness; cost optimisation and business-model potential; renewable-energy integration and avoided curtailment potential; flexibility service readiness; data governance; skills development; institutional learning; and scalability across European contexts.

At the D4.4 evidence cut-off, the assessment distinguishes between confirmed pilot-readiness evidence, documented technical and data capabilities, modelled or simulated flexibility potential, and monitored impact indicators that are being validated through partner reporting and stakeholder survey evidence. This distinction ensures that the assessment remains transparent and methodologically robust, while still recognising the progress achieved in preparing the pilots for socio-economic, economic and environmental evaluation.

The socio-economic value of FlexCHESS is further strengthened by the project's Key Exploitable Results (KERs), which translate the technical outputs of the project into reusable, scalable and potentially marketable assets. These include real-time digital twins for hybrid storage optimisation, an energy management system for distributed HESS optimisation, the VESS concept and VSoC estimator, CHESS-plug, data analytics and machine-learning tools, decision-making tools for VESSs, smart contracts, innovative forecasting systems and a shared knowledge base for VESS. These KERs support the project's wider impact by enabling flexibility-market readiness, improved system efficiency, better renewable-energy integration, new digital-energy services, and future exploitation by DSOs, energy communities, aggregators, technology providers and commercial/industrial users.

Key findings demonstrate that FlexCHESS has a credible pathway to socio-economic and environmental value where multiple assets can be coordinated through CHESS Nodes and FlexPlatform tools. The strongest expected benefits include improved DER coordination, increased renewable-energy use, enhanced self-consumption, demand response, peak shaving, load shifting, EV smart charging, DSO flexibility, island-grid resilience and improved decision-making for future energy-system planning. The main barriers identified relate to data availability, real-time integration, market-readiness, user incentives, comfort and automation concerns, and the need for clear communication with non-technical stakeholders.

D4.4 impact quantification is structured to integrate partner-validated data on energy savings, flexibility activations, curtailment reduction, cost savings, response times, service success rates and stakeholder satisfaction scores. As these values are consolidated, the assessment can move from a readiness- and potential-based evaluation towards a fully evidenced impact assessment of the FlexCHESS pilot demonstrations.

2 D4.4 – Socio-Economic & Environmental Impact Assessment

This deliverable provides a socio-economic and environmental assessment of the FlexCHESS pilots, demonstrating benefits beyond technology, including societal value, market viability and policy relevance, in line with Horizon Europe requirements.

3 Introduction

3.1 Context and Objectives

The FlexCHESS project, funded under Horizon Europe Grant Agreement No. 101096946, addresses a central challenge of the energy transition: how to increase the value and usability of distributed energy resources (DERs) by making them interoperable, controllable and available for flexibility services. FlexCHESS developed and tested Connected Hybrid Energy Storage Systems (CHESS), which aggregate different energy assets - including Battery Energy Storage Systems (BESS), Electric Vehicles (EVs), PV systems, flexible loads, HVAC/refrigeration units, heat pumps and other controllable resources - through CHESS Nodes and the wider FlexPlatform. The FlexPlatform acts as the digital coordination layer for forecasting, asset registration, optimisation, decision support, smart energy management, flexibility service provision, digital-twin interaction and knowledge/data sharing across pilot contexts.

The core concept of FlexCHESS is to allow production units, consumption units and storage assets to interact dynamically, adjusting production, consumption or storage behaviour in response to system needs. FlexCHESS aims to provide flexibility services by aggregating multiple CHESSs that operate collaboratively within a CHESS Node, thereby allowing the value of flexibility to be shared among the actors involved.

This deliverable, D4.4, is produced under Task 4.3 and focuses on the socio-economic and environmental assessment of the FlexCHESS pilots. It complements the technical validation work of WP4 by examining the wider value of the pilot demonstrations: not only whether the technology functions, but also whether it creates meaningful social, economic, environmental and institutional benefits.

The assessment therefore provides evidence in four main areas:

- **Societal value:** social acceptance, stakeholder engagement, perceived usefulness, trust, user participation, behaviour change and skills development.
- **Economic viability:** cost-effectiveness, asset utilisation, cost-saving potential, business-model relevance and flexibility-market readiness.
- **Environmental benefit:** renewable-energy integration, curtailment reduction potential, emissions-reduction pathways, storage optimisation and resource-efficiency considerations.
- **Policy and replication relevance:** regulatory alignment, interoperability, scalability, replicability across EU contexts and contribution to future flexibility-market design.

The assessment builds on the pilot-preparation evidence of datasets for DERs across the five pilot sites, identifying available assets, accessible historical or real-time data, and controllable parameters. It also maps the FlexPlatform tools required for implementation, including forecasting, real-time digital twins, decision-support systems, flexibility service providers, smart energy management tools and the Open Knowledge Platform.

Accordingly, D4.4 uses a mixed assessment approach combining stakeholder engagement, S-LCA-informed analysis, life cycle cost analysis, ex-ante environmental assessment, review of pilot-readiness evidence, KER/exploitation evidence and cross-pilot comparison. Where monitored M26-M42 operational data are not harmonised across all pilots, the assessment classifies evidence as confirmed documentary evidence, partner-reported evidence, modelled/simulated evidence or validation data, rather than treating the information as a single undifferentiated dataset.

3.2 Pilot Sites Overview

Five pilot sites were established across different European contexts, enabling FlexCHESS to test its approach in varied technical, institutional and social environments. The pilots represent a deliberately diverse portfolio: an industrial/simulation context in Wales, a DSO-led flexibility context in Slovenia, a renewable energy community in Spain, a multi-building energy optimisation and EV charging context in Italy, and an island energy-community/grid-stability context in Turkey.

3.2.1 Pilot Sites Overview table

Pilot	Owner / Partner	Location	Profile	Confirmed / Identified Assets and Data Context	Relevant Use Cases
Welsh Pilot	Cardiff University (CU)	Neath Port Talbot / Swansea Bay, Wales, UK	FLEXIS demonstration area; simulation-supported industrial and energy-system context	Local electricity and gas networks; two biomass power stations; CCGT power station; solar farm; wind farm; proposed tidal lagoon; behind-the-metre renewables and storage; industrial loads including steelworks, water treatment plant, cement works and paper mill; public/commercial load. Data used to support simulation study.	UC1 / UC3-oriented simulation evidence, including VESS for industrial buildings

Pilot	Owner / Partner	Location	Profile	Confirmed / Identified Assets and Data Context	Relevant Use Cases
Slovenian Pilot	Elektro Ljubljana (EL)	Slovenia	DSO-led flexibility and EMSP/EV context	EV charging stations, PV systems, flexible residential load subject to volunteer participation; real-time data including EV SOC, DG forecasting, grid frequency and ADMS-SCADA data; controllable parameters include EV charging/discharging and flexible-load consumption.	UC1 Peak Shaving, UC2 Frequency Regulation, UC4 Smart EV Charging
Spanish Pilot	La Solar / MIW	Bullas, Murcia, Spain	Renewable Energy Community / local solar cooperative	Air-conditioning units, DHW tanks, PV plants, heat pumps or small split units, batteries; real-time/pilot data include electricity price, load, heat-pump consumption, battery SOC and PV output, with controllable heat-pump status and battery charging/discharging. The workshop scenario also includes a 50 kWh residential battery for REC subscription and a solar + battery day-ahead optimisation case.	UC1 Peak Shaving and UC3 Renewable Energy Community

Pilot	Owner / Partner	Location	Profile	Confirmed / Identified Assets and Data Context	Relevant Use Cases
Italian Pilot	IREN	Turin, Italy	Energy utility / multi-building optimisation, EV charging and PV/BESS integration	Refrigeration / HVAC units, EVs and AC recharging stations, battery storage and rooftop PV. Available data include historical PV output, historical HVAC data, electricity price, PV output, BESS telemetry, EV charging power and HVAC data. Controllable parameters include BESS charging/discharging and EV charging signals. The IREN deployment specification further confirms BESS data/control adapters, HVAC/PV data adapters, EV charging-station adapters, UUDEX/RabbitMQ, and FlexPlatform optimisation tools.	UC1 Peak Shaving, UC1 Load Shifting, UC4 Energy and Cost Optimisation for Commercial Buildings, UC4 Smart EV Charging
Turkish Pilot	UEDAS	Gökçeada Island, Çanakkale Province, Turkey	DSO / island energy community focused on grid stability and frequency regulation	Island grid connected to mainland by submarine cable; 2 wind turbines totalling 1.8 MW; 0.21 MWp PV plant; CHESS assets including battery, heat pump and EV; smart metres on consumers. D4.2	UC2 Load Balancing and UC2 Frequency Regulation

Pilot	Owner / Partner	Location	Profile	Confirmed / Identified Assets and Data Context	Relevant Use Cases
				also identifies a 100 kWh BESS, 16 kW air-to-air heat pump and 22 kW EV charging station, with power load, EV SOC, battery SOC and renewable-generation data to be used where available.	

The documentation confirms the relevant DER categories, several capacities and data/control parameters for each pilot. D4.2 explicitly identifies which datasets and controllable DER parameters are available or expected for each pilot; however, it also notes that some data remain reference values because engineering practices and implementation considerations were still ongoing.

The above table is used as the validated pilot-readiness and assessment baseline. Installed capacity, operating periods, monitored performance values and partner-confirmed asset status are treated as validation data and are incorporated where documented in WP4 pilot operation reports, workshop evidence or partner data returns.

3.3 Use Cases Implemented

The FlexCHESS pilots are structured around four use cases, further divided into eight operational scenarios and distributed across the five pilot contexts. D4.2 identifies the DER combinations selected for integration into FlexCHESS Nodes, subsequently confirmed through pilot deployment and validation in D4.3, while the implementation strategy for each pilot identifies the relevant FlexPlatform tools and controlled assets.

The use cases are:
UC1: Powering Grid Resilience via Demand Response
UC1 focuses on demand response, peak shaving and load shifting. It supports DSO-driven flexibility by enabling assets to reduce or shift consumption during periods of grid stress, congestion or high demand. Relevant pilots include Slovenia, Spain and Italy for peak shaving, with Italy also addressing load shifting and longer-term behavioural engagement.

UC2: Empowering Grid Stability via Dynamic Energy Response

UC2 addresses load balancing and frequency regulation. It is particularly relevant for pilots where grid stability and DSO/TSO coordination are central concerns. The Turkish Gökçeada pilot is directly aligned with load balancing and frequency regulation due to its island-grid conditions, renewable variability and limited backup options. Slovenia is also relevant for frequency regulation and DSO flexibility through EV charging, PV systems, ADMS-SCADA data and flexible loads.

UC3: Virtual Power Plants and Renewable Energy Communities Supporting Grid Integration
UC3 supports the aggregation of DERs through VESS/VPP-type configurations and renewable energy communities. The Welsh pilot contributes simulation-based evidence for VESS in industrial buildings, while the Spanish pilot is strongly aligned with the Renewable Energy Community scenario. The Turkish pilot also contributes to the renewable-energy community dimension through the Gökçeada island-energy context.

UC4: Adaptive Energy Management
UC4 focuses on energy and cost optimisation for commercial buildings and smart charging of EV communities. It is particularly relevant for the Italian IREN pilot, where EV charging, PV, BESS, HVAC/refrigeration assets and multi-building optimisation are combined. Slovenia is also linked to smart EV charging, with EV charging stations and SOC data forming part of the pilot dataset.

Across these use cases, the FlexPlatform provides the enabling technical layer. D4.2 identifies forecasting tools, real-time digital twins, decision-support systems, flexibility service provider functionality, smart energy management and open knowledge/data collection tools as core components supporting the pilot scenarios. These tools provide the basis for calculation of socio-economic, environmental and cost-effectiveness indicators, including flexibility availability, flexibility activation, response time, energy shifting, user engagement, renewable-energy use and system-level value.

4 Methodology and Assessment Framework

A mixed-methods approach combined quantitative technical data from pilot operators with qualitative perception and behavioural data collected directly from stakeholders.

4.1 Assessment Dimensions

The framework evaluates four complementary dimensions:

1. Socio-Economic Impact (S-LCA aligned) – stakeholder categories, impact pathways, perception, acceptance

2. Economic Assessment (LCCA & cost-effectiveness) – CAPEX/OPEX, revenue streams, cost-benefit ratios

3. Environmental Impact (LCA & curtailment analysis) – CO_2 emissions reduction, RES integration, curtailment minimisation

4. Institutional & Market Readiness – regulatory compliance, policy alignment, scalability potential

4.2 Methodological Approaches

The D4.4 assessment applies a mixed-methods framework combining technical pilot evidence, socio-economic analysis, environmental screening, cost-effectiveness logic and stakeholder feedback. This approach reflects the nature of FlexCHESS as both a technological demonstration and a socio-technical intervention: the pilots are not assessed only in terms of whether the platform operates, but also in terms of whether the solutions are acceptable, understandable, economically meaningful, environmentally relevant and replicable.

The methodology draws on four main evidence streams already available within the project:

1. **WP4 technical and pilot-preparation evidence**, including D4.2, pilot workshop material and CHESS Node / Digital Twin deployment documentation;
2. **Pilot results and validation evidence** from D4.3 (Report on Pilot Sites Results), including KPI validation tables, real-data demonstrations and pilot-operator findings.
3. **Pilot-specific DER datasets**, including available assets, historical or real-time data streams and controllable parameters;
4. **T4.3 stakeholder-engagement tools**
5. **Cross-pilot qualitative analysis**, including barriers, enablers, perceived benefits and replication potential identified through pilot preparation and technical workshops.
6. **Key Exploitable Results and Business Model Canvas evidence**, including the GA-listed KERs and partner-specific exploitation models, which support the assessment of market readiness, scalability, business-model viability and post-project socio-economic value.

D4.2 provides an important methodological foundation because it identifies the available DERs in each pilot site, the historical and real-time data expected from these assets, and the controllable parameters relevant to flexibility provision. This dataset supports the assessment of pilot readiness, flexibility potential and the feasibility of socio-economic and environmental impact measurement.

4.2.1 Methodological Framework tabe – D4.4

Method	Application in D4.4	Data Sources / Evidence Base	Treatment in This Deliverable
Social Life Cycle Assessment-informed analysis (S-LCA)	Assesses social impacts and risks for relevant stakeholder categories, including energy communities, prosumers, DSOs, pilot operators,	T4.3 stakeholder survey; partner input; workshop evidence; pilot descriptions; country/pilot	Used as a structured social-impact lens rather than a full quantified S-LCA

Method	**Application in D4.4**	**Data Sources / Evidence Base**	**Treatment in This Deliverable**
	local communities, public authorities and technical/value-chain actors.	context; future PSILCA indicators where available.	
Stakeholder survey analysis	Measures awareness, perceived usefulness, acceptance, barriers, trust, behaviour change, satisfaction and willingness to participate in flexibility services.	T4.3 Socio-Economic Impact Survey prepared for dissemination through Microsoft Forms.	Survey instrument exists and is GDPR-framed.
Semi-structured qualitative interpretation	Captures perceived benefits, implementation barriers, user concerns, trust issues, usability questions and socio-economic value pathways.	Pilot workshops, partner discussions, technical deployment material and open survey responses.	Used to interpret barriers and enablers where formal survey data are not yet complete.
Technical readiness review	Establishes what each pilot can credibly assess, based on installed or planned DERs, data streams and controllable parameters.	D4.3; D4.2 DER dataset; pilot workshop slides; CHESS Node and Digital Twin guides.	Used to distinguish between measured impacts, simulated/modelled impacts and indicators.
Life Cycle Cost Analysis (LCCA)	Assesses CAPEX, OPEX, lifetime costs, payback period and long-term economic viability.	Pilot financial data; business model inputs; partner cost estimates; deployment specifications.	Applied where cost data are available
Cost-effectiveness analysis	Calculates or prepares calculation of cost per kWh of flexibility, cost per kW of flexible capacity, cost per tCO_2 avoided, avoided-cost	Pilot operational data; flexibility activations; tariff/market assumptions;	Used as a structured economic framework.

Method	**Application in D4.4**	**Data Sources / Evidence Base**	**Treatment in This Deliverable**
	potential, and benefit–cost logic.	FME/modelled values; market price benchmarks.	
Ex-ante environmental assessment / LCA screening	Assesses emissions-reduction potential, renewable-energy integration, curtailment reduction, resource efficiency and battery-use impacts.	Equipment specifications; energy consumption/generation data; battery and PV data; national grid factors; pilot monitoring data.	Conducted as an ex-ante or screening-level assessment unless full ISO 14040/14044 LCA inventory data are provided.
Before–after comparison	Compares baseline consumption/generation/flexibility conditions with post-implementation or simulated FlexCHESS performance.	Pilot monitoring data; historical data; D4.2 baseline data categories; D4.3 post-implementation pilot results; simulation outputs.	Applicable where baseline and post-implementation data exist. Where pilots are simulation-based or partially deployed, results are reported as modelled rather than measured.
Cross-pilot comparison	Identifies common success factors, barriers, replication conditions and pilot-specific value cases.	Evidence from all five pilots: Wales, Slovenia, Spain, Italy and Turkey.	Used to compare social, economic, environmental and institutional readiness across different contexts.
Workshop-based technical consultation	Provides evidence of stakeholder alignment, use-case refinement, technical feasibility, data availability and implementation risks.	Pilot site workshop presentations and WP4 technical material.	Treated as structured technical consultation rather than formal social focus groups.

The table above describes the methodological framework applied in D4.4, showing each method's application, evidence base, and treatment within this deliverable.

4.2.2 Data Status and Methodological Classification table

Evidence Type	**Definition**	**How Used in D4.4**
Confirmed documentary evidence	Information directly available in D4.2, D4.3, pilot workshop files, technical deployment guides and survey documentation.	Used to describe assets, data streams, use cases, platform capabilities and assessment readiness.
Partner-reported / survey evidence	Responses from T4.3 survey, partner interviews or partner data templates.	Used for acceptance, satisfaction, behaviour change and stakeholder-perception findings.

The table above describes the evidence types used in D4.4 and their application within the deliverable.

5 Key Performance Indicators (KPIs)

The D4.4 assessment uses a combined KPI framework covering technical, functional, economic, environmental and socio-economic performance. The purpose of this framework is to connect the technical demonstration of FlexCHESS with its wider socio-economic and environmental value. The KPIs therefore assess not only whether the FlexCHESS platform and CHESS Nodes function correctly, but also whether the pilots can generate usable flexibility, support renewable-energy integration, reduce costs, improve stakeholder acceptance and provide evidence for replication.

The KPI framework builds on the use-case structure defined in D1.5 and urther operationalised in D4.2 and validated against pilot performance in D4.3. The four use cases are divided into eight scenarios and assigned across the five pilot sites. These include peak shaving, load shifting, load balancing, frequency regulation, VESS for industrial buildings, renewable-energy community support, commercial-building energy optimisation and smart EV charging.

5.1.1 Technical KPIs table

Technical KPIs evaluate the ability of FlexCHESS Nodes, FlexPlatform tools and associated data systems to register, monitor, optimise and control distributed energy resources. They are particularly important because the pilots combine different asset types, data environments and operational constraints.

KPI	Definition / Measurement Logic	Relevance to D4.4
CHESS Utilisation Efficiency (%)	Share of available flexibility that is actually used or activated during a flexibility event.	Measures whether available flexible assets are operationally useful, not merely installed.
Interoperability Latency / Response Time	Time required for signals, requests or control actions to move between assets, CHESS Nodes, FlexPlatform tools and external systems.	Relevant for all use cases, especially frequency regulation, load balancing and smart charging.
Data Transmission Success Rate (%)	Proportion of successful data exchanges between field assets, gateways, CHESS Nodes, Digital Twin components, FlexPlatform tools and platform databases.	Indicates reliability of the digital infrastructure and quality of monitoring data.
Managed Flexibility Components / Assets (%)	Share of identified assets that are successfully registered, monitored or controlled through the FlexCHESS architecture.	Connects pilot asset readiness with socio-economic and environmental assessment capacity.
Minimum Response Requirement Compliance	Whether the FlexCHESS Node can meet the response-time, minimum-power and duration requirements defined per scenario.	D4.2 defines deployment requirements across scenarios, including 15–60 minutes for peak shaving, load shifting, load balancing, RE community and commercial-building optimisation; ≤1 second for frequency regulation; and 1 minute–15

KPI	Definition / Measurement Logic	Relevance to D4.4
		minutes for VESS industrial flexibility.
Digital Twin / API Readiness	Ability to represent CHESS assets digitally and access/query/update asset status through APIs, Digital Twin Explorer, AAS submodels and CHESS status/capacity interfaces.	Supports traceability, interoperability and future verification of flexibility actions.

The table above describes the technical performance KPIs used in D4.4 to assess the operational readiness and interoperability of the FlexCHESS architecture.

The pilot workshops identify a focused D1.5 KPI set: CHESS Utilisation Efficiency, Source Contribution, Load Shifting Capability, Interoperability Latency, Flexibility Index and Service Efficiency. These KPIs are intended to be measured during pilot execution and used to validate FlexCHESS performance.

5.1.2 Functional KPIs table

Functional KPIs assess whether the relevant use cases, scenarios and asset-management functions are practically enabled in the pilots.

KPI	Definition / Measurement Logic	Relevance to D4.4
Use Case Coverage (%)	Share of planned use cases/scenarios addressed in each pilot.	Confirms the breadth of the demonstration across the five European pilots.
Pilot Assets Eligible for Flexibility Mechanisms (%)	Share of identified pilot assets technically and operationally able to participate in flexibility services.	Shows whether DERs are usable for flexibility, not only present on site.
Flexibility Request Satisfaction Rate (%)	Share of flexibility requests fulfilled successfully, either through real activation, simulated market operation or scheduled optimisation.	Connects technical functionality with system usefulness.

KPI	Definition / Measurement Logic	Relevance to D4.4
Asset Management Functionality Coverage (%)	Share of required asset functions covered: registration, monitoring, forecasting, optimisation, control, scheduling and reporting.	Indicates maturity of the platform and CHESS Node deployment.
Pilot Feasibility Level	Qualitative assessment of readiness: high, medium or low feasibility, based on data availability, integration complexity, platform maturity and risk.	Useful where final operational data are not yet harmonised.
MVP Readiness	Whether a pilot can demonstrate a minimum viable FlexCHESS implementation using available features.	The Spanish workshop, for example, rated the Bullas REC scenario as highly feasible for MVP with FME simulation, while noting that real market integration remains the main gap.

The table above describes the pilot-level KPIs used in D4.4 to assess demonstration coverage, asset readiness and flexibility performance across the FlexCHESS pilots.

The uploaded pilot workshops used a structured feasibility framework assessing technical feasibility, data availability, integration complexity and risk level. This framework is useful for D4.4 because it provides a defensible way to distinguish between fully ready, partially ready and future-phase functionalities.

5.1.3 Economic KPIs table

Economic KPIs assess whether FlexCHESS can support financially meaningful flexibility services, cost optimisation, reduced operational expenditure, deferred system costs or future business models.

KPI	Definition / Measurement Logic	Relevance to D4.4
Integration Cost (EUR / GBP)	Cost of connecting assets, gateways, CHESS Nodes, software, APIs, communications and	Required for cost-effectiveness and replication analysis.

KPI	Definition / Measurement Logic	Relevance to D4.4
	supporting infrastructure.	
CAPEX per Asset / Pilot	Capital expenditure for equipment, installation, batteries, EV chargers, metres, control systems and integration.	Required for LCCA and payback-period estimation.
OPEX per Asset / Pilot	Annual operational cost including maintenance, hosting, licences, communication, staff time and data management.	Supports full life cycle cost analysis.
Cost per kWh of Flexibility	Annualised cost divided by kWh shifted, stored, discharged or activated.	Main cost-effectiveness indicator.
Cost per kW of Flexible Capacity	Annualised cost divided by kW of available flexible capacity.	Useful for comparing pilots with different scales and asset mixes.
Service Efficiency	Revenue or avoided cost compared with cost of flexibility provision.	One of the D1.5 KPI categories identified in the workshop material.
Flexibility Revenue / Simulated Revenue	Revenue from real or simulated flexibility markets, including FME-based testing.	Must distinguish between actual market income and modelled/simulated market potential.
Energy Cost Savings	Reduced bills or avoided peak costs through load shifting, smart charging, self-consumption or optimisation.	Relevant for Spain, Italy, Slovenia and Turkey.
Payback Period	Initial investment divided by annual net benefit.	Important for business-model viability and replication.

The table above describes the economic and cost-effectiveness KPIs used in D4.4 to assess the financial viability and replication potential of the FlexCHESS pilots.

The Slovenian pilot provides a clear economic logic for EV smart charging: by optimising charging schedules, users can reduce costs during expensive peak periods and maximise charging during cheaper off-peak or favourable tariff periods. The same section notes that centralised management of EV charging stations simplifies smart-charging coordination and can support DSO benefits such as constraint management.

For Spain, the Renewable Energy Community scenario is associated with self-consumption optimisation, cost optimisation and market participation through FME simulation. The Spanish workshop confirms that historical PV production, load consumption profiles, battery specifications and OMIE historical data are available or identified as data sources, while real market integration remains a later-phase gap.

5.1.4 Environmental KPIs table

Environmental KPIs assess whether FlexCHESS contributes to renewable-energy integration, avoided curtailment, reduced emissions and more efficient use of distributed assets.

KPI	Definition / Measurement Logic	Relevance to D4.4
CO_2 Emissions Reduction (tCO_2/year)	Estimated emissions avoided through increased renewable use, reduced grid imports, optimised load shifting or avoided fossil-based balancing.	Main environmental impact indicator.
RES Integration Rate (%)	Share of renewable generation used locally or integrated into the energy system rather than curtailed or exported without optimisation.	Particularly relevant for Spain, Italy and Turkey.
Curtailment Reduction (%) / kWh	Difference between renewable energy curtailed before and after FlexCHESS intervention, or under baseline versus optimised scenarios.	Measures environmental and economic value of storage/flexibility.
Load Shifting Capability (kWh)	Amount of demand shifted from peak or carbon-intensive periods to off-peak or renewable-rich periods.	Identified as a D1.5 KPI in the workshop material.
Source Contribution (%)	Contribution of each asset/source — PV, battery, EV,	Allows environmental value to be linked to

KPI	Definition / Measurement Logic	Relevance to D4.4
	heat pump, HVAC, flexible load — to total flexibility provision.	asset type.
Battery / Asset Utilisation and Degradation Consideration	Tracks whether battery use is optimised to avoid unnecessary degradation while still providing flexibility.	Relevant to circular economy and life-cycle impact assessment.

The table above describes the environmental KPIs used in D4.4 to assess the emissions reduction, renewable integration and resource efficiency achieved through the FlexCHESS pilots.

The FlexPlatform includes forecasting tools for renewable-energy production and electricity consumption, real-time digital twins, decision-support systems, smart energy-management tools and FSP functionality. These tools provide the technical basis for environmental optimisation, including improved use of PV/wind generation, better load scheduling and real-time balancing.

5.1.5 Socio-Economic KPIs table

Socio-economic KPIs assess whether FlexCHESS is accepted, understood and perceived as beneficial by stakeholders, and whether it creates wider value through participation, capacity building and behaviour change.

KPI	Definition / Measurement Logic	Relevance to D4.4
Stakeholder Satisfaction Score	Average satisfaction score from T4.3 survey responses, using the scale included in the Microsoft Forms survey.	Primary social acceptance indicator.
Community Acceptance Rate (%)	Share of respondents indicating willingness to participate in or support FlexCHESS-enabled flexibility services.	Especially relevant for Spain and Turkey energy-community contexts.
Perceived Benefit Score	Stakeholder rating of benefits such as cost savings, renewable-energy use, energy autonomy, reliability or comfort.	Connects technical outcomes to user/social value.
Perceived Barrier Score / Qualitative	Frequency and severity of barriers such as complexity,	Supports policy and replication

KPI	Definition / Measurement Logic	Relevance to D4.4
Barriers	privacy concerns, automation concerns, comfort impacts, unclear incentives or market uncertainty.	recommendations.
Behaviour Change Indicators	Evidence of changes in energy-use awareness, willingness to shift demand, participation in smart charging, or engagement with energy monitoring.	Relevant for load shifting, REC participation and smart EV charging.
Trust and Data Governance Indicators	Stakeholder confidence in data handling, privacy, automated control and platform reliability.	Important for GDPR, digital twin and smart-metre contexts.
Skills and Capacity-Building Indicators	Number/type of stakeholders trained, technical staff engaged, or new competencies developed.	Captures institutional learning and future replication capacity.
Job Creation / Labour Input (FTE or staff hours)	New roles, additional staff time, installation/maintenance work or operational effort required.	Useful but likely limited at pilot scale; should be reported carefully.

The table above describes the social KPIs used in D4.4 to assess stakeholder acceptance, perceived benefits and behaviour change across the FlexCHESS pilots.

6 Socio-Economic Impact Assessment (S-LCA Aligned)

6.1 Framework and Stakeholder Categories

The socio-economic impact assessment of FlexCHESS is informed by the logic of Social Life Cycle Assessment (S-LCA), adapted to the scale and maturity of the project's pilot demonstrations. Rather than applying S-LCA as a fully quantified database-driven exercise at this stage, the assessment uses an S-LCA-aligned framework to identify relevant stakeholder groups, map potential impact pathways, and assess social acceptance, perceived benefits, barriers and socio-economic value across the five pilot contexts.

This approach is appropriate for FlexCHESS because the project is not only a technical demonstration of Hybrid Energy Storage Systems (HESS), but also a socio-technical intervention. The project connects energy assets, digital platforms, flexibility services, energy communities, DSOs, EV users, building operators and technical actors. D4.2 confirms that FlexCHESS aims to provide flexibility services by aggregating multiple connected hybrid energy storage systems operating within CHESS Nodes, enabling production and consumption units to interact by adjusting production or consumption according to flexibility needs.

The assessment therefore considers five main stakeholder categories.

Stakeholder category	Relevance to FlexCHESS	Relevant pilot contexts	Main impact areas assessed
Energy Communities / Prosumers	Residential, municipal or small commercial participants who may provide flexibility through PV, batteries, heat pumps, EVs or flexible loads.	Spain / Bullas REC; Turkey / Gökçeada; Slovenia where flexible residential loads or EV participation are involved.	Energy autonomy, self-consumption, cost savings, willingness to participate, trust, data privacy, fairness of benefit distribution.
Local Communities	Residents, municipalities and local stakeholders affected by renewable-energy use, grid stability, energy-community models or public energy assets.	Spain, Turkey, Wales, Slovenia.	Community engagement, awareness, environmental quality, local acceptance, local resilience, public value.
Industry / Commercial Users	Large energy users, building managers, facility managers, industrial operators and fleet/EV charging managers.	Italy / IREN; Wales / FLEXIS industrial context; Slovenia EV charging context.	Operational flexibility, cost optimisation, peak reduction, energy management, continuity of operations, comfort and service quality.
Public Authorities / System Actors	DSOs, regulatory bodies, municipalities and actors responsible	Slovenia / Elektro Ljubljana; Turkey / UEDAS; Italy / IREN; Spain	Grid stability, congestion management, peak demand

Stakeholder category	Relevance to FlexCHESS	Relevant pilot contexts	Main impact areas assessed
	for grid reliability, energy policy and flexibility-market readiness.	municipal/REC context.	management, regulatory compliance, policy learning and replication.
Value Chain Workers / Technical Operators	Installers, technicians, developers, energy managers, platform operators, data engineers and maintenance staff.	All pilots.	Skills development, technical capacity, occupational safety, operational workload, digital upskilling and future employment pathways.

The table above describes the stakeholder categories assessed in D4.4, their relevance to FlexCHESS, associated pilot contexts, and the main impact areas evaluated for each.

The impact categories are structured as follows:

Stakeholder group	Impact categories assessed
Energy communities / prosumers	Energy cost savings, energy autonomy, renewable self-consumption, participation in decision-making, access to flexibility services, privacy and data security, clarity of incentives.
Local communities	Local engagement, energy awareness, environmental quality, local resilience, community empowerment, public trust in energy innovation.
Industry / commercial users	Operational flexibility, reduced peak demand, cost competitiveness, continuity of service, comfort management, regulatory and ESG alignment.
Public authorities / system actors	Grid stability, avoided or deferred network interventions, peak-demand management, policy learning, market-readiness and replication.
Value chain workers	Technical skills, digital energy-management capacity,

Stakeholder group	Impact categories assessed
/ technical operators	workload implications, health and safety, quality of working conditions, future job potential.

The table above describes the impact categories assessed for each stakeholder group considered in D4.4.

6.2 S-LCA reference framework (UNEP 2020): impact subcategories applied to FlexCHESS

To ensure methodological alignment with the UNEP/SETAC Guidelines for the Social Life Cycle Assessment of Products and Organisations (UNEP 2020) and the associated Methodological Sheets (UNEP 2021), the five FlexCHESS stakeholder categories defined above are mapped to the six standard S-LCA impact categories, human rights, working conditions, health and safety, cultural heritage, governance and socio-economic repercussions, and to the impact subcategories used in the established S-LCA literature. Of the approximately forty subcategories defined in the UNEP framework, around thirty are assessed as material to a distributed-flexibility intervention of this type. Subcategories tied to upstream extraction, agriculture or armed conflict are screened out as not material to the pilot activities, while subcategories relating to working conditions, health and safety, consumer data protection, governance, local-community engagement and socio-economic development are retained as the structured social-impact lens applied throughout Section 6.

Impact subcategory (UNEP 2020 / 2021)	Relevance to FlexCHESS	Primary FlexCHESS impact pathway / treatment
Workers (working conditions, human rights, health & safety)		
Freedom of association & collective bargaining	Selected	Conditions of employment for installers, technicians, data engineers and platform operators across the consortium.
Fair salary	Selected	Quality of technical and value-chain roles sustained or created through pilot operation and future flexibility services.
Working hours	Selected	Operational workload associated with running CHESS Nodes, monitoring and flexibility-service provision.
Health and safety	Selected	Occupational safety in the installation and maintenance of BESS, EV chargers, heat pumps and electrical assets.

Impact subcategory (UNEP 2020 / 2021)	Relevance to FlexCHESS	Primary FlexCHESS impact pathway / treatment
Equal opportunities / non-discrimination	Selected	Inclusive access to skills development and to energy-community participation.
Social benefits / social security	Selected	Employment conditions of staff engaged in pilot deployment and operation.
Employment relationship	Selected	Formality and security of roles in installation, integration and operation.
Child labour	Screened out	Not material to EU/UK/Turkey pilot operations; upstream battery and electronics supply-chain risk addressed via the LCA in Section 8.
Forced labour	Screened out	Upstream raw-material supply risk only; addressed through value-chain and LCA screening rather than primary pilot data.
Sexual harassment	Screened out	No project-specific evidence; governed by partner HR frameworks and national law.
Smallholders including farmers	Screened out	Not relevant to the energy-flexibility value chain.
Local community		
Access to material resources	Selected	Reliable and affordable local energy supply; island-grid resilience (Turkey) and REC self-consumption (Spain).
Access to immaterial resources	Selected	Energy literacy, awareness and access to flexibility services.
Community engagement	Selected	REC participation in Bullas (Spain) and island-community engagement in Gökçeada (Turkey).
Local employment	Selected	Local technical, maintenance and energy-community facilitation roles.
Safe & healthy living conditions	Selected	Grid reliability and reduced local emissions through optimised renewable use.
Secure living conditions	Selected	Energy security and resilience, particularly in constrained and island grids.
Delocalisation and	Screened	Not applicable to the pilot interventions.

Impact subcategory (UNEP 2020 / 2021)	**Relevance to FlexCHESS**	**Primary FlexCHESS impact pathway / treatment**
migration	out	
Cultural heritage	Screened out	Low materiality for the pilot activities.
Respect of indigenous rights	Screened out	Not applicable in the pilot contexts.
Value-chain actors		
Fair competition	Selected	Open APIs and interoperability (AAS, UUDEX) that avoid vendor lock-in and enable market entry.
Supplier relationships	Selected	Consortium and technology-provider relationships underpinning deployment.
Respect of intellectual property rights	Selected	KER/IP handling and smart-contract traceability of flexibility transactions.
Promoting social responsibility	Selected	Diffusion of responsible flexibility-service and data-governance practices along the chain.
Wealth distribution	Selected	Fair allocation of flexibility value among prosumers, aggregators, operators and DSOs.
Consumers (prosumers and end-users)		
Consumer privacy	Selected	GDPR-compliant handling of metering, EV-charging and consumption data (Section 6.5; Annex 1).
Transparency	Selected	Clear communication of what is monitored, why, and how benefits are allocated.
Feedback mechanism	Selected	User override, consent and complaint channels for automated control.
Health and safety	Selected	Safe operation of consumer-side assets (EV chargers, heat pumps, smart plugs).
End-of-life responsibility	Selected	Battery and electronics end-of-life; quantified through the LCA in Section 8.
Society		
Contribution to	Selected	Flexibility-market development, skills

Impact subcategory (UNEP 2020 / 2021)	Relevance to FlexCHESS	Primary FlexCHESS impact pathway / treatment
economic development		creation and exploitable results (KERs).
Technology development	Selected	Digital twins, forecasting, VESS and interoperability advances.
Public commitments to sustainability issues	Selected	Contribution to EU climate and energy-transition objectives.
Corruption (governance)	Selected	Transparent procurement and auditable, smart-contract-based transaction logic.
Poverty alleviation	Selected	Energy-cost reduction and energy-poverty mitigation potential in community/REC contexts.
Prevention & mitigation of armed conflicts	Screened out	Not material to the pilot activities.
Ethical treatment of animals	Screened out	Not applicable.
Children (UNEP 2020 addition)		
Education in the local community	Contextual	Indirect awareness/education benefit via community engagement; not separately quantified.
Health & marketing concerns for children	Screened out	No child-directed product or marketing dimension in the pilots.

The selected subcategories are operationalised through the stakeholder-survey indicators (Sections 6.3–6.5), the employment and skills analysis (Section 6.6) and the country-level social-risk screening (Section 6.2). Screened-out subcategories are documented for transparency and to satisfy the completeness requirement of the UNEP 2020 framework; where they relate to upstream supply chains (e.g. child labour, forced labour, end-of-life responsibility), they are addressed through the environmental life-cycle assessment in Section 8 rather than through primary pilot data.

6.2 Country-Level Social Risk Context (PSILCA)

The original methodology envisaged the use of PSILCA indicators to contextualise social risk across the countries involved in the pilots: the UK/Wales, Slovenia, Spain, Italy and Turkey. Relevant PSILCA dimensions would include labour rights, occupational health and safety, governance, access to infrastructure, community conditions, and broader country-level social-risk factors.

For methodological transparency, D4.4 therefore treats PSILCA as a recommended contextual layer rather than a completed quantitative component. The absence of PSILCA data does not prevent the socio-economic assessment, because project-specific evidence is available from D4.2, pilot workshop material, the digital twin/CHESS deployment documents. However, PSILCA or an equivalent social-risk screening would strengthen the final version by providing country-level context for worker, community and governance-related risks.

In the absence of a completed PSILCA extraction, the country-level context is framed qualitatively as follows:

Pilot country / context	**Social-risk context relevant to D4.4**	**Treatment in this assessment**
UK / Wales	Industrial and energy-system context; simulation-based FlexCHESS evidence using the FLEXIS demonstration area.	Treated primarily as a simulation and system-learning context rather than a direct end-user social acceptance case.
Slovenia	DSO-led flexibility, EV charging, PV systems and possible flexible residential-load participation.	Focus on public/system value, EV-user participation, data reliability and DSO flexibility.
Spain	Renewable Energy Community in Bullas involving residential and municipal participants.	Strongest context for community acceptance, benefit distribution, participation and energy autonomy.
Italy	Utility/multi-building site with EV charging, PV, battery and HVAC/refrigeration assets.	Strongest context for commercial-user acceptance, facility management, comfort protection and operational cost optimisation.
Turkey	Island energy-community and DSO context in Gökçeada, with wind, PV, battery, heat pump, EV assets and grid-stability needs.	Strong context for resilience, renewable integration and public/system value, but with higher technical complexity.

The table above summarises the social-risk context relevant to D4.4 across the five FlexCHESS pilot countries, together with how each context is treated within this assessment.

6.3 Stakeholder Perception and Acceptance

Stakeholder perception and acceptance are central to FlexCHESS because the project depends on the willingness of different actors to allow energy assets to be monitored, aggregated and optimised for flexibility services. Acceptance is not expected to be uniform across all stakeholder groups. Technical partners, DSOs and pilot operators are likely to show higher acceptance because they understand the operational benefits of flexibility. End-users, prosumers and building occupants may be more cautious, especially where automated control, personal consumption data, EV charging behaviour or thermal comfort are involved.

Based on the uploaded material, expected acceptance patterns can be summarised as follows:

Pilot	**Likely acceptance profile**	**Supporting evidence from uploaded material**	**Main acceptance considerations**
Spain / Bullas REC	High potential acceptance due to community-energy structure and visible local benefits.	The Spanish pilot site identifies Bullas as a Renewable Energy Community with 18+ participants, 7 prosumers with PV plants, 3 batteries, and a municipal office with 5 kW PV and a battery	Acceptance depends on clarity of benefit distribution, participation rules, data privacy and ease of onboarding.
Italy / IREN	High acceptance among facility/technical stakeholders; moderate acceptance among building occupants or EV users if comfort and convenience are protected.	The Italian pilot site identifies the site as a corporate facility with office buildings, multi-storey parking, refrigeration/HVAC units, EV charging, company EV fleet, rooftop PV and planned battery installation. It also frames the FlexCHESS value as harmonising consumption, storing excess energy, redistributing during	Acceptance depends on comfort-aware HVAC control, predictable EV charging, user override options and clear communication.

Pilot	Likely acceptance profile	Supporting evidence from uploaded material	Main acceptance considerations
		peaks and coordinating EV charging.	
Slovenia / Elektro Ljubljana	Medium–high acceptance among DSO/system actors; conditional acceptance among EV users and residential participants.	D4.2 identifies Slovenian assets as EV charging stations, flexible residential load requiring volunteers, and PV systems, with data including EV SOC, DG forecasting, grid frequency and ADMS-SCADA data. D4.3's Pilot 2 (Slovenian Pilot – EV Community Based VESS) results section provides the corresponding acceptance and uptake evidence.	Acceptance depends on incentives, EV charging reliability, user consent and data governance.
Turkey / Gökçeada	Medium–high acceptance where resilience and renewable-energy integration are understood as public benefits.	D4.2 identifies Turkish assets including a 100 kWh battery, 16 kW air-to-air heat pump and 22 kW EV charging station, with data on load, EV SOC, battery SOC and PV/wind generation. D4.3's Table 7 (Validation of claims and KPIs at the Turkish pilot, p.100) confirms the validated performance of these assets.	Acceptance depends on perceived grid-stability value, reliability, public communication and confidence in automated balancing.

Pilot	Likely acceptance profile	Supporting evidence from uploaded material	Main acceptance considerations
UK / Wales	More limited direct user acceptance evidence because the pilot is simulation-supported.	D4.3 reports the Welsh FLEXIS demonstration area simulation results in FlexCHESS (Pilot 1, Scenario A/B delivery power curves, Figures 8–9), covering local networks, power generation, storage, industrial loads and public/commercial load.	Useful for industrial/system learning, but less suitable for direct claims about community or end-user acceptance.

Overall, the available evidence supports a cautiously positive assessment of stakeholder acceptance, particularly among technical and institutional actors. The main acceptance risks are not opposition to the concept of flexibility itself, but practical concerns: privacy, complexity, automation, comfort, convenience, unclear incentives and uncertainty about real-market benefits.

6.4 Behavioural Change and Engagement

Behavioural change in FlexCHESS should be understood in two ways. First, there is direct behavioural change, where users actively adjust charging, consumption or participation patterns. Second, there is indirect behavioural change, where automated energy-management systems shift consumption while users remain informed, consenting and able to retain control.

At the current stage, FlexCHESS behavioural impact comes through enabled behaviour and structured engagement, rather than large-scale manual behaviour change. The platform and CHESS Node approach allows assets to be registered, aggregated and optimised, reducing the need for constant user action. However, users still need to understand the value of flexibility, accept participation and trust how their assets and data are managed.

The key behavioural pathways are:

Behavioural pathway	Description	Most relevant pilots
Energy awareness	Users become more aware of energy timing, PV production, peak periods and flexible consumption.	Spain, Slovenia, Italy, Turkey
Load shifting	Consumption or charging is shifted to off-peak or renewable-rich periods.	Spain, Italy, Slovenia
Smart EV charging participation	EV users allow charging to be scheduled or optimised while still meeting mobility needs.	Italy, Slovenia, Turkey
Renewable self-consumption behaviour	Energy-community participants understand the value of using locally generated renewable energy.	Spain, Turkey
Trust in automated optimisation	Users accept that automated systems can improve costs, grid stability or self-consumption without reducing comfort or control.	Italy, Slovenia, Spain
Institutional learning	DSOs, utilities and technical partners adapt working practices around flexibility, forecasting, digital twins and CHESS Nodes.	All pilots

D4.3 provides evidence that these behavioural pathways are technically relevant. For Italy, the real IREN peak-shaving and cost-optimisation demonstrations (Figures 46–49) show monitoring of real-time demand, EV charging-station demand and battery SOC, with charging schedules adjusted to delay or reduce charging during peak periods. It also confirms cost optimisation through real-time electricity prices, building consumption, PV forecasts and battery SOC, with charging scheduled during low-price periods and reduced during high-cost periods.

For Spain, engagement is linked to energy-community participation. The Spanish workshop describes an asset-onboarding and Renewable Energy Community subscription workflow, including battery asset creation, geocoding, REC CHESS Node creation, member invitation, acceptance, rulebook validation and active subscription. This shows that behavioural engagement is not only about electricity consumption; it also includes the social process of joining, accepting and participating in an energy-community flexibility structure.

For Slovenia, D4.2 notes that flexible residential load requires volunteers. This is important because it shows that social participation and consent remain necessary for at least part of the flexibility model.

6.5 Perceived Benefits, Barriers and Social Risks

The uploaded material supports the identification of both positive socio-economic pathways and practical barriers. FlexCHESS is likely to be perceived positively where the value proposition is clear: lower energy costs, better renewable-energy use, improved grid stability, reduced peaks, smarter EV charging, and greater energy autonomy. At the same time, the material points to implementation barriers that may affect social acceptance and replicability.

6.5.1 Perceived Benefits table

Benefit	Description	Main pilots
Energy cost optimisation	Charging, battery use and consumption can be shifted according to prices, PV availability and demand peaks.	Italy, Spain, Slovenia
Renewable-energy self-consumption	PV and wind generation can be better matched with storage and demand.	Spain, Italy, Turkey
Grid stability and resilience	Flexibility can support load balancing, frequency regulation and DSO operations.	Turkey, Slovenia
Community empowerment	RECs can support local participation and shared energy value.	Spain, Turkey
Operational efficiency	Facility operators can optimise buildings, EV charging and storage in coordinated ways.	Italy
Institutional learning	DSOs, utilities and technical partners learn how to deploy flexibility services across multiple regulatory contexts.	All pilots

The FlexPlatform architecture supports these benefits through forecasting, real-time digital twins, decision support, flexibility service provision, smart energy management and an Open Knowledge Platform. D4.2 identifies these as core tools for implementing the use cases across the pilots.

6.5.2 Barriers and Risks table

Barrier / risk	Relevance to socio-economic assessment	Mitigation logic
Complexity of flexibility concepts	Non-technical users may not easily understand CHESS Nodes, aggregation, digital twins or market participation.	Use simple public-facing explanations and pilot-specific examples.
Data privacy and trust	Smart metres, EV charging data, consumption profiles and automated control may raise concerns.	Maintain GDPR-compliant survey and data governance; communicate what is monitored and why.
Comfort impacts	HVAC or flexible-load control may raise concerns among building occupants.	Use comfort-aware control, pre-cooling strategies and override options.
EV convenience	Users may worry that smart charging will interfere with mobility needs.	Guarantee minimum SOC / departure-time requirements and clear override options.
Market uncertainty	Some value streams are currently simulated rather than connected to real markets.	Distinguish between FME-modelled value and actual market revenues.
Integration barriers	SCADA, BMS, APIs, digital twins, MQTT, EV chargers and data formats may delay implementation.	Use phased MVP implementation and partner technical-validation workshops.
Unequal benefit distribution	Energy-community members may question who benefits and how revenues are allocated.	Define transparent rulebooks, allocation rules and communication processes.

The Spanish workshop explicitly notes that the Flexibility Market Emulator is used for market simulation and is not yet connected to real markets, while also identifying platform functions such as asset registration, CHESS Node management, rulebook validation and FSP orchestration. This supports a transparent reporting approach:

social acceptance should be assessed against both current MVP capability and future production-readiness.

6.6 Employment and Skills Development

At pilot scale, FlexCHESS is not expected to generate large direct employment numbers. However, it has clear relevance for skills development, technical capacity-building and future labour-market opportunities in energy flexibility, digital energy systems and distributed-resource management.

The main employment and skills impacts are expected in the following areas:

Skills / employment area	**Relevance to FlexCHESS**
Digital energy management	Technical partners and operators gain experience with CHESS Nodes, FlexPlatform tools, digital twins and flexibility workflows.
Data integration and interoperability	Staff develop capacity in APIs, smart-metre data, SCADA/ADMS, BMS integration, MQTT, Kafka/EventBus, digital twins and AAS models.
Energy-community operation	REC managers and local energy actors gain knowledge in member onboarding, compliance validation, self-consumption optimisation and benefit allocation.
EV smart charging management	Operators learn to manage EV charging schedules, user constraints, battery SOC and flexibility availability.
Facility and building optimisation	Building managers and technical staff gain skills in peak shaving, load shifting, HVAC flexibility and PV/battery optimisation.
DSO flexibility operations	DSOs gain experience in near-real-time flexibility, load balancing, frequency regulation, activation monitoring and system-service design.

The pilot workshop material shows that workshops were designed not only for technical review, but also for learning and capacity building: objectives included gaining knowledge of the FlexCHESS platform architecture, hands-on interaction with modules, alignment of pilot use cases with platform maturity, feedback collection and implementation planning. This is a clear capacity-building outcome of WP4 and T4.3.

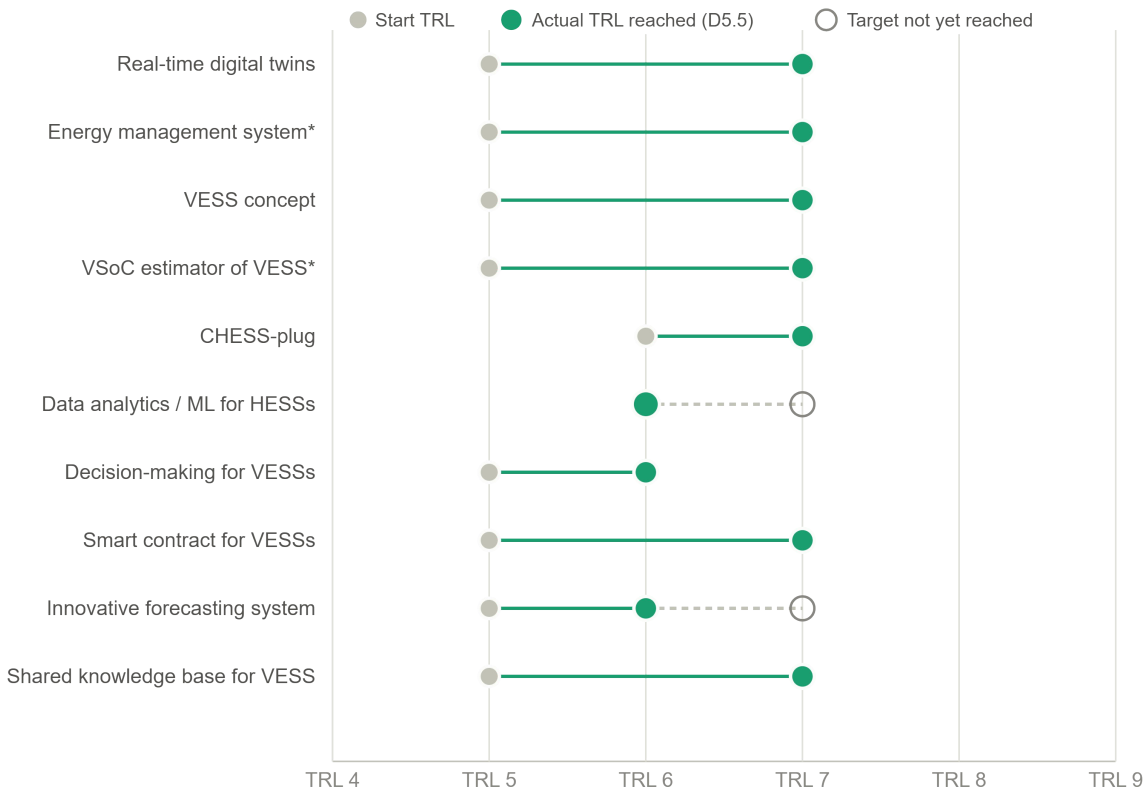
Employment impacts should therefore be reported carefully. The immediate impact is best described as skills development and institutional capacity-building, rather than confirmed job creation. Future employment potential may arise in installation, maintenance, flexibility aggregation, data management, platform operation, smart charging management, energy-community facilitation and digital-twin services.

Direct job creation at pilot scale is expected to be limited and should not be overstated. The more immediate socio-economic contribution of FlexCHESS lies in skills development and institutional learning. Across the pilots, technical partners, DSOs, facility managers and energy-community actors are exposed to new competencies in digital energy management, DER integration, smart charging, forecasting, optimisation, digital twins, flexibility-service workflows and data governance. These skills are relevant to future replication and market uptake of flexibility services in Europe.

6.7 Key Exploitable Results and Socio-Economic Value

In addition to assessing the socio-economic and environmental value of the five pilots, D4.4 considers the Key Exploitable Results (KERs) generated by FlexCHESS. These KERs are important because they represent the project outputs with the strongest potential for reuse, replication, commercialisation, further research, policy uptake or service development after the end of the project.

The Grant Agreement identified several KERs with expected TRL progression, typically from TRL 5 or 6 towards TRL 7. By the end of the project, most KERs met or reached their target TRL, as confirmed in D5.5 (Key Exploitable Results); two — AI forecasting and ML data analytics models (AMU/ALWA) — reached TRL 6, one level below their TRL 7 target. These results are not only technical achievements; they also have socio-economic relevance because they enable new flexibility services, improve the usability of distributed energy resources, support renewable-energy integration, and create new business and market opportunities for the FlexCHESS partners and future adopters.



Expected versus actual TRL progression per Key Exploitable Result (KER). Grey markers indicate the TRL at project start; teal markers indicate the TRL actually reached, as reported in D5.5 (Key Exploitable Results). Hollow markers indicate the Grant Agreement's target TRL where this had not yet been reached by project end. All KERs met or reached their expected target, with the exception of AI forecasting and ML data analytics models (AMU/ALWA), which reached TRL 6 against a TRL 7 target.

The KERs indicate three important avenuew. First, they show that FlexCHESS produces reusable results beyond the individual pilot sites. Second, they create a bridge between technical validation and exploitation by identifying which outputs can become services, tools, APIs, platforms or business models. Third, they help demonstrate post-project value for stakeholders such as DSOs, aggregators, energy communities, commercial and industrial sites, technology providers, researchers and policymakers.

Key Exploitable Result	Lead / Partner(s)	Expected TRL progression	Socio-economic relevance for D4.4
Real-time digital twins for distributed hybrid energy storage optimisation	Toshiba	TRL 5 -> 7	Supports transparent monitoring, optimisation and interoperability of hybrid storage assets, improving trust, system efficiency and replication potential.
Energy	Toshiba /	TRL 5 -> 7	Enables charge/discharge

management system for distributed hybrid energy storage optimisation	AMU		optimisation according to overall goals, supporting cost savings, energy efficiency and improved use of flexible assets.
VESS concept	Cardiff University	TRL 5 -> 7	Increases the flexibility of VPPs by sharing storage capacity across distributed resources and increasing self-consumption of green generation.
VSoC estimator of VESS	Cardiff University	TRL 5 -> 7	Provides an API/software tool to estimate available power and energy capacities, improving flexibility planning and operational decision-making.
CHESS-plug	Arcelik	TRL 6 -> 7	Enhances smart plug capabilities for energy-consumption, temperature, current and voltage data collection, supporting user-level flexibility and optimisation scenarios.
Data analytics / Machine learning for HESSs	AMU	TRL 6 -> 7	Improves scalability and modularity of data-analytics applications and supports real-time extraction of valuable information from energy curves.
Decision-making for VESSs	AMU	TRL 5 -> 6	Develops ML-based flexibility-index logic, supporting eligibility analysis, decision-making and profitability of FlexCHESS installations.
Smart contract for VESSs	RDIUP	TRL 5 -> 7	Improves encryption, traceability and transparency in flexibility transactions, supporting trust, accountability and future market participation.
Innovative system for forecasting	AMU	TRL 5 -> 7	Improves renewable-energy production forecasting and energy-management optimisation, strengthening flexibility and RES integration.

Shared knowledge base for VESS	ALWA, Toshiba, AMU, RDIUP, CU	TRL 5 -> 7	Structures and normalises VESS/VPP knowledge, supporting replication, capacity building and knowledge transfer across partners and future users.

The table above summarises the ten Key Exploitable Results (KERs) generated by FlexCHESS, their lead and contributing partners, expected TRL progression as defined in the Grant Agreement, and their socio-economic relevance for D4.4.

The socio-economic value of the KERs is particularly visible in relation to skills development and institutional learning. Digital twins, forecasting tools, VESS decision-making, smart contracts and shared knowledge bases require new capacities in data management, energy optimisation, flexibility-market logic, cybersecurity, interoperability and user engagement. These capacities are important for the future labour market around distributed energy systems and flexibility services.

At the same time, the KERs are reported as exploitable project outputs with demonstrated or emerging validation, rather than as fully commercialised products. Their exploitation potential depends on partner-confirmed pilot results, TRL validation, market access, regulatory conditions, user acceptance, business-model maturity and continued post-project development.

6.8 Summary of Findings for Section 6

The S-LCA-aligned assessment indicates that FlexCHESS has a credible socio-economic value proposition across the five pilot contexts. The strongest expected impacts are:

- improved energy autonomy and participation in the Spanish REC context;
- improved facility-level cost and energy optimisation in the Italian pilot;
- DSO flexibility and EV smart-charging value in Slovenia;
- island-grid resilience and renewable integration in Turkey;
- system-learning and industrial flexibility modelling in Wales.

The main barriers are complexity, data privacy, automation concerns, comfort and convenience risks, integration challenges and uncertainty around real-market monetisation.

Taken together, the S-LCA-aligned findings support the central socio-economic claim of FlexCHESS: that the project delivers value to society as a whole, and not only to the individual asset owner or operator. Public authorities and DSOs benefit from improved grid stability, congestion relief and deferred network reinforcement; energy communities and prosumers benefit from lower energy costs, higher renewable self-consumption and greater energy autonomy; consumers and local communities benefit from a more reliable, resilient and lower-carbon energy supply; and the wider value chain benefits from new skills, interoperable tools and exploitable results that can be replicated across Europe. These distributed benefits, combined with a predominantly low country-level social-risk context, provide an evidence-based foundation on which public authorities, the energy community and other key stakeholders can support the future uptake of FlexCHESS solutions.

7 Economic Assessment: Cost-Effectiveness and LCCA

The economic assessment examines whether FlexCHESS can create financial and system-level value through the coordination of distributed energy resources, storage assets, EV charging, flexible loads and digital optimisation tools. The assessment combines Life Cycle Cost Analysis (LCCA), cost-effectiveness logic and business-model interpretation, and is developed in conjunction with the findings of D5.5 (Incentive-based business model), which provides the project's CAPEX/OPEX estimates, revenue models and Business Model Canvases for the FlexPlatform tools and CHESS Node services. It considers both direct economic benefits, such as energy cost savings or potential flexibility revenues, and wider system benefits, such as avoided peak demand, improved renewable-energy use, reduced congestion and support for DSO/TSO flexibility needs.

The financial figures available for the pilots are treated as initial estimates or partner-reported assumptions rather than audited deployment costs, consistent with the evidence status of the corresponding figures in D5.5. CAPEX, OPEX, revenue and payback values are therefore classified according to their evidence status: documented, partner-reported, simulated/modelled or validation data. The workshop material nevertheless provides a strong basis for identifying the economic value pathways of each pilot.

The FlexPlatform tools are designed to support forecasting, real-time digital twins, high-level decision support, flexibility-service provision, smart energy management and knowledge/data sharing. These tools provide the operational basis for economic value creation, including storage sizing, flexibility activation, smart charging, peak reduction, energy-cost optimisation and coordination of DERs across CHESS Nodes.

7.1 Investment Costs (CAPEX)

Initial investment requirements vary significantly across the five pilots because the pilot contexts differ in scale, asset composition, level of existing infrastructure and integration complexity. Some pilots rely primarily on software integration and platform connection, while others involve batteries, EV charging infrastructure, monitoring systems, communication units, IoT devices or building-energy-management integration.

7.1.1 Investment Costs (CAPEX) table

Pilot	Estimated CAPEX / Initial Investment	Main Components	Economic Interpretation
Spanish Pilot – La Solar / Bullas REC	Approx. €500 per user	IoT devices, energy-management system, smart metering/control, CHESS integration, REC participation workflow	Low-cost, community-oriented model. Economic viability depends on number of participating users, self-consumption gains, avoided grid imports and future community-level flexibility value.
Welsh Pilot – Cardiff University / FLEXIS	Approx. £252,150	Battery energy storage, control systems, measurement and communication units	Higher investment profile, but mainly relevant as simulation/system-learning evidence. Economic conclusions should be presented as modelled rather than fully operational unless live pilot cost data are available.
Slovenian Pilot – Elektro Ljubljana	Approx. €15,000	Software upgrade, FlexPlatform integration, EV charging / DSO flexibility interfaces	Relatively low investment profile if existing EV charging, SCADA/ADMS and DSO infrastructure are leveraged. Value is linked to DSO flexibility, smart charging and avoided constraint-management costs.
Italian Pilot –	Approx.	IT services, battery installation, CHESS	Strong investment case due to multi-building

Pilot	Estimated CAPEX / Initial Investment	Main Components	Economic Interpretation
IREN	€40,000–€50,000	Node hosting, PV/BESS/EV/HVAC integration, data interfaces	optimisation, EV charging coordination, PV self-consumption, battery use and peak-demand reduction.
Turkish Pilot – UEDAS / Gökçeada	Approx. €10,000	Server rental, CHESS components, integration of battery/heat pump/EV assets, DSO/island-grid data connection	Investment value should be assessed against resilience, island-grid stability, renewable integration and balancing/frequency support, not only direct revenue.

Each pilot has a distinct set of available assets and controllable parameters. For example, the Spanish pilot includes air-conditioning units, DHW tanks, PV plants, heat pumps or split units, and batteries; the Italian pilot includes refrigeration/HVAC units, EVs and AC charging stations, battery storage and rooftop PV; and the Turkish pilot includes a 100 kWh battery energy storage system, a 16 kW air-to-air heat pump and a 22 kW EV charging station.

The estimates above are used as the current economic baseline and are to be consolidated with partner-confirmed values for equipment, installation, integration, software, cloud/server, communication, licensing and staff-time costs.

7.2 Operational Costs (OPEX)

Operational costs are expected to include maintenance, software or platform hosting, data communication, server/cloud services, technical monitoring, staff time, equipment servicing and, where relevant, battery and EV charging infrastructure maintenance.

7.2.1 Operational Costs (OPEX) table

Pilot	Estimated OPEX	Main Components	Economic Interpretation
Spanish Pilot	Expected to be minimised through IoT-based operation	Communication-device maintenance, smart metering, platform connection, local support	Low operational cost is important for REC scalability. OPEX must remain low enough to preserve user/community benefit.
Welsh Pilot	Approx. £5,000/year or around 2% of CAPEX	Battery maintenance, monitoring/control systems	Should be interpreted in relation to the simulation or modelled flexibility value unless live operational use is confirmed.
Slovenian Pilot	Approx. €250 per asset	EV charging stations, PV maintenance, software/data interface maintenance	OPEX is linked to the number of flexible assets integrated. Smart charging and DSO benefits must justify per-asset operating costs.
Italian Pilot	Being consolidated	Energy, maintenance, IT services, personnel time, battery/EV/HVAC/PV data integration, CHESS Node hosting	OPEX should be assessed against multi-building energy savings, avoided peak costs, PV self-consumption and EV charging optimisation.
Turkish Pilot	Approx. €5,000/year per asset	Server rental, data management, CHESS component maintenance, asset monitoring	OPEX should be assessed against resilience and grid-stability value as well as direct flexibility-service potential.

Smart energy-management tools can reduce operational costs, provide ancillary services and enhance the grid's ability to handle peak demand while minimising reliance on carbon-intensive power sources. This directly supports the economic case for OPEX where recurring operating costs enable ongoing optimisation and flexibility provision.

7.3 Revenue Streams and Cost Savings

The main revenue and saving pathways differ by pilot because FlexCHESS is tested in different market, community, building and DSO contexts. For this reason, the economic assessment should not rely on a single revenue model. Instead, it should use a value-stack approach, combining direct energy savings, avoided operational costs, simulated or future flexibility revenues, renewable self-consumption benefits and system-level avoided costs.

7.3.1 Main Revenue and Saving Categories

Value stream	Description	Most relevant pilots
Energy bill savings	Reduced energy costs through peak shaving, load shifting, smart charging and use of low-cost tariff periods.	Spain, Italy, Slovenia
PV self-consumption optimisation	Increased use of locally generated PV rather than importing from the grid or exporting at lower value.	Spain, Italy
Battery optimisation	Charging during low-cost or high-renewable periods and discharging during high-cost or high-demand periods.	Spain, Italy, Turkey
EV smart charging savings	Scheduling EV charging according to price, availability, user needs and grid conditions.	Italy, Slovenia, Turkey
Flexibility-service revenue	Revenue from flexibility markets or simulated flexibility services, including DSO/TSO requests.	Slovenia, Italy, Spain, Turkey
Avoided grid or operational costs	Avoided congestion, reduced peak load, deferred reinforcement, reduced balancing interventions.	Slovenia, Turkey, Italy
Ancillary service	Frequency response, load balancing, voltage support or other system	Slovenia,

Value stream	Description	Most relevant pilots
potential	services.	Turkey, Wales
Community value	Shared benefits through REC participation, self-consumption, local energy autonomy and member-level optimisation.	Spain, Turkey

For Slovenia, D4.2 identifies EVs as a controllable and centrally managed resource. It states that smart charging can help users minimise costs during expensive peak periods and maximise energy use during cheaper off-peak periods or favourable tariffs. It also notes that centrally managed EV charging stations simplify implementation and can provide benefits such as constraint management to DSOs.

For Italy, D4.3 provides one of the strongest cost-saving pathways. The FlexPlatform monitors real-time building demand, EV charging demand and battery SOC, identifies upcoming peaks, adjusts EV charging schedules, and uses battery discharge to support building demand during peak periods. It also uses real-time electricity prices, building consumption, PV forecasts and battery SOC to schedule EV charging and battery charging during low-price periods, and reduce grid energy use during high-cost periods.

For Spain, the workshop material confirms that the Bullas Renewable Energy Community scenario aims to maximise self-consumption, optimise costs and enable market participation. It also confirms that key data are available or identified, including historical PV production, load consumption profiles, battery specifications and OMIE historical day-ahead market prices. However, real market integration is not yet available and the Flexibility Market Emulator is used for MVP testing.

7.4 Cost-Effectiveness Analysis

Cost-effectiveness measures whether the benefits of FlexCHESS justify the investment and operational costs required to deploy and maintain the system. Because the pilots differ significantly, the assessment should compare both direct financial returns and system-level value.

The following indicators form the calculation framework for partner-validated economic data:

7.4.1 Cost-Effectiveness Analysis table

Indicator	Calculation Logic	Purpose
Cost per kWh of flexibility provided	Annualised cost / kWh shifted, stored, discharged or activated	Measures the cost of usable flexibility.
Cost per kW of flexible capacity	Annualised cost / kW of flexible capacity available	Allows comparison across pilot sizes and asset mixes.
Cost per tCO_2 avoided	Annualised cost / tCO_2 avoided	Links economic and environmental value.
Payback period	Initial investment / annual net benefit	Measures time needed to recover investment.
Net Present Value (NPV)	Discounted benefits – discounted costs	Assesses long-term investment attractiveness.
Internal Rate of Return (IRR)	Discount rate at which NPV = 0	Indicates financial performance of the investment.
Benefit–Cost Ratio	Present value of benefits / present value of costs	Shows whether expected benefits exceed costs.
Service efficiency	Revenue or avoided cost / cost of flexibility provision	Captures whether flexibility services are economically useful.

The project's KPI logic also supports cost-effectiveness assessment. The Spanish workshop identifies KPIs including CHESS Utilisation Efficiency, Source Contribution, Load Shifting Capability, Interoperability Latency, Flexibility Index and Service Efficiency. Service Efficiency is especially relevant to economic assessment because it links the revenue or value of flexibility to the cost of providing it.

7.4.2 Pilot-specific cost-effectiveness interpretation table

Pilot	Cost-effectiveness logic
Spain	Strongest where REC participation increases PV self-consumption, reduces grid imports, supports battery use and produces member-level cost savings. Revenue figures for this pathway are currently based on simulated market prices rather than live transactions, since the pilot has not yet been integrated with OMIE (Spain's Nominated Electricity Market Operator) or an equivalent market operator; these figures should therefore continue to be treated as simulated/modelled until such integration is in place.
Italy	Strong cost-effectiveness case due to multiple value streams: peak shaving, PV self-consumption, EV charging optimisation, battery use and multi-building demand management.
Slovenia	Cost-effectiveness depends on whether EV smart charging and flexibility activation reduce DSO constraints and user charging costs.
Turkey	Cost-effectiveness should include resilience and island-grid stability value, not only direct financial return. The 100 kWh BESS, heat pump and EV charger provide flexibility for load balancing and renewable integration.
Wales	Economic outputs should be reported as modelled or simulation-based unless live operational cost and performance data are available.

7.5 Business Model Viability

The business-model assessment should recognise that FlexCHESS does not correspond to a single commercial model. The pilots suggest several potential pathways, depending on whether the customer is an energy community, DSO, facility operator, EV charging operator, industrial site or aggregator.

From the D5.5 business-model assessment, three revenue models were identified:

Pay-as-you-use

Users or system actors pay according to metered flexibility provision, service activation, optimisation use or platform interaction. This model is most relevant where flexibility activations can be measured and monetised.

Subscription fees

A fixed periodic fee is paid for access to CHESS Node services, FlexPlatform functions, monitoring, forecasting, optimisation or REC/flexibility-management tools. This may be suitable for energy communities, commercial buildings or DSOs seeking ongoing service support.

Direct sales

Equipment, installation, integration and platform access are sold as a package. This model may apply where customers require physical assets such as batteries, smart metres, IoT devices or EV charging integration alongside software access.

Based on the uploaded evidence, each pilot suggests a different business-model emphasis:

Pilot	Most relevant model(s)	Rationale
Spain / Bullas REC	Subscription + pay-as-you-use	REC members may benefit from shared platform services, self-consumption optimisation and future flexibility allocation.
Italy / IREN	Direct sales + service subscription	Multi-building optimisation may require installation/integration plus ongoing energy-management services.
Slovenia / Elektro Ljubljana	Pay-as-you-use + DSO service model	Flexibility activation and EV smart charging can be linked to service delivery and constraint management.
Turkey / UEDAS	DSO/resilience service model + direct integration	Island-grid resilience may justify investment through avoided system risk and improved renewable integration.
Wales / CU	Simulation / decision-support model	Useful for modelling, planning and VESS design rather than immediate end-user commercial deployment.

The strongest near-term business viability appears in pilots where FlexCHESS creates multiple benefits at once. Italy combines energy-cost optimisation, peak shaving, EV charging coordination and PV/BESS integration. Spain combines REC management, PV self-consumption, batteries and community-level value. Slovenia and Turkey provide strong system-value cases where flexibility may support DSOs, grid stability and avoided operational interventions.

The Business Model Canvas material produced by the consortium provides additional evidence that the KERs are not only technical outputs, but exploitable assets with emerging market pathways. The AMU BMC identifies possible revenue streams including SaaS subscription access to the FlexCHESS platform and microservices, API usage fees for forecasting and optimisation, licensing of proprietary algorithms, consulting and integration services, revenue sharing on multi-market flexibility valorisation, and further research/public funding.

The IREN BMC frames the future FlexPlatform as a post-project solution for DSOs, aggregators, asset owners and energy utilities. It identifies value propositions around optimisation and harmonisation of distributed assets, forecasting of controllable-asset usage, energy and cost optimisation, peak shaving and load shifting. It also identifies potential revenue streams including platform licences, implementation support, maintenance support, personalisation costs and revenue schemes based on a percentage of customer savings.

The Toshiba BMC provides a further exploitation pathway, positioning FlexCHESS for commercial and industrial site owners, data-centre operators, BESS/EVCS integrators, DNOs, TSOs and flexibility-market actors. It identifies digital twins, optimisation engines, marketplace layers, forecasting, asset modelling and customer onboarding as core activities, with revenue streams including performance-based fees, SaaS subscriptions, onboarding fees, marketplace transaction cuts and professional services.

Together, these BMCs show that FlexCHESS has several possible exploitation routes: platform-as-a-service, API-based services, algorithm licensing, integration and consulting, performance-based savings models, flexibility-market revenue sharing, and partner-led deployment through DSOs, utilities, aggregators and technology integrators. This strengthens the economic assessment by demonstrating that the KERs can support future business models, even where final pilot revenue data are still pending.

7.6 Interim Economic Conclusion

The available evidence suggests that FlexCHESS has a credible economic value proposition. Operational monitoring data and validated savings or revenue figures, will be quantified as partner data is consolidated. The most mature economic value cases are those where multiple value streams are stacked: energy-cost reduction, self-consumption, load shifting, peak shaving, flexibility provision and system-level avoided costs.

The assessment therefore distinguishes between:

• confirmed economic mechanisms, such as smart charging, peak shaving, battery optimisation and PV self-consumption;

• modelled or simulated market potential, especially where the Flexibility Market Emulator is used instead of real market integration;

• validation-stage quantified results, including measured energy savings, revenues, OPEX, payback and avoided costs.

8 Environmental Impact Assessment: Curtailment and LCA

8.1 Curtailment Reduction

One of the primary environmental benefits of FlexCHESS is its potential to reduce renewable energy curtailment by improving the coordination between renewable generation, storage assets, flexible loads and energy consumption. Curtailment occurs when renewable electricity, particularly from PV or wind, cannot be used, stored or exported due to grid constraints, demand mismatch, technical limitations or market conditions. By using CHESS Nodes, battery storage, EV charging, heat pumps, HVAC flexibility and demand-response logic, FlexCHESS supports the time-shifting of consumption and the storage or local use of excess renewable generation.

The curtailment-reduction potential is particularly relevant in pilots with significant renewable generation or renewable-community structures. The Spanish pilot is based on a Renewable Energy Community in Bullas, with PV assets, batteries and community participants. The Italian pilot includes rooftop PV, battery storage, EV charging stations and HVAC/refrigeration assets. The Turkish Gökçeada pilot includes two 0.9 MW wind turbines, a 0.21 MWp PV plant, a 100 kWh battery energy storage system, a 16 kW air-to-air heat pump and a 22 kW EV charging station, making it particularly relevant for renewable integration in an island-grid context.

For D4.4, curtailment should be assessed through the following indicators:

Indicator	Definition	Data required
Baseline curtailment rate	Renewable generation curtailed before FlexCHESS intervention	Historical PV/wind generation, export limits, unmet generation
Post-implementation curtailment rate	Renewable generation curtailed after CHESS optimisation	Monitored or simulated pilot data
Renewable energy saved from curtailment	kWh of renewable electricity stored, shifted or consumed instead of curtailed	Battery, PV, wind, load and storage data
Economic value of avoided curtailment	Monetary value of renewable electricity that would otherwise be wasted	Market price, tariff, avoided import cost or local valuation
Flexibility contribution to	Share of avoided curtailment enabled by BESS, EV	Asset-level contribution data

Indicator	Definition	Data required
curtailment reduction	charging, HVAC or load shifting	

At the D4.4 evidence cut-off, curtailment figures are not harmonised across all pilots. The assessment therefore distinguishes between confirmed curtailment-reduction potential, where assets and data streams are available, and measured or simulated curtailment reduction, where pilot monitoring or simulation outputs are available.

8.2 CO_2 Emissions Reduction

FlexCHESS contributes to CO_2 reduction through several pathways: increasing local use of renewable energy, reducing reliance on grid imports during high-carbon or peak periods, enabling battery-supported load shifting, and improving the efficiency of energy use across buildings, EV charging and community assets.

The FlexPlatform includes forecasting tools, real-time digital twins, decision-support systems, flexibility service providers, smart energy-management tools and an Open Knowledge Platform. These tools provide the technical basis for environmental optimisation by forecasting renewable production, electricity consumption and grid/storage conditions.

The main emissions-reduction pathways are:

Pathway	Environmental logic	Relevant pilots
Increased renewable self-consumption	More locally generated PV/wind is used directly or stored instead of being curtailed or exported at low value	Spain, Italy, Turkey
Load shifting	Consumption is shifted away from peak or high-carbon periods	Italy, Spain, Slovenia
Smart EV charging	EV charging is scheduled during low-cost, low-carbon or renewable-rich periods	Italy, Slovenia, Turkey
Battery optimisation	Batteries charge during renewable-rich or low-carbon periods and discharge during peaks	Spain, Italy, Turkey
DSO flexibility	Flexibility reduces the need for inefficient	Slovenia, Turkey

Pathway	Environmental logic	Relevant pilots
	balancing or reinforcement responses	
Island-grid resilience	Local flexibility reduces vulnerability and improves renewable integration in constrained grid systems	Turkey

For the Italian pilot, the FlexPlatform can use real-time electricity prices, building consumption, PV production forecasts and battery SOC to schedule EV charging and battery charging during low-price periods, while reducing grid energy use during high-cost periods. The same logic can support emissions reductions when low-price periods correlate with higher renewable availability or lower carbon intensity.

The following indicators provide the calculation framework for monitored or simulated emissions data:

Indicator	Required input
Baseline grid emissions intensity	gCO_2/kWh per pilot country or local grid area
Renewable energy used locally	kWh PV/wind consumed directly or through storage
Renewable energy saved from curtailment	kWh previously curtailed or unused
Load shifted	kWh shifted from peak/high-carbon periods
Battery discharge replacing grid imports	kWh supplied from battery instead of grid
EV charging optimisation	kWh charged during low-carbon or renewable-rich periods
Net emissions reduction	tCO_2/year per pilot

At the D4.4 evidence cut-off, emissions reduction is reported as potential, modelled or measured according to the available evidence for each pilot.

8.3 Ex-Ante Life Cycle Assessment (LCA)

A full ISO 14040/14044-compliant LCA inventory is not included in the uploaded material. D4.4 therefore presents the LCA component as an ex-ante environmental screening rather than a complete quantified LCA, which is methodologically appropriate when stated transparently.

The ex-ante LCA considers the likely environmental effects of FlexCHESS across the main life-cycle stages:

Life-cycle stage	**Environmental aspects to consider**
Manufacturing	Embodied carbon in batteries, EV charging equipment, inverters, control devices, gateways, communication equipment and ICT infrastructure
Transport and installation	Delivery and installation of batteries, chargers, IoT devices and supporting equipment
Operation	Electricity consumption of control systems, digital infrastructure, monitoring systems and asset operation
Environmental benefits during operation	Avoided grid imports, reduced curtailment, increased renewable self-consumption, optimised EV charging, reduced peaks
End of life	Battery recycling, EV battery reuse, electronics disposal, recovery of critical raw materials

The pilots differ significantly in their LCA relevance. Italy and Turkey involve physical battery, EV and control-system assets and therefore require closer attention to embodied carbon and operational benefits. Spain has strong relevance for PV self-consumption and community-scale optimisation. Slovenia is particularly relevant for EV charging and DSO flexibility. Wales is more relevant for simulation-based environmental scenario analysis than for direct asset-level LCA.

A practical approach is to classify environmental impact evidence as follows:

Evidence category	**How to report**
Confirmed asset-based potential	Report where DERs, batteries, EVs, PV/wind and controllable loads are identified
Modelled	Report where scenario or simulation data estimate avoided

Evidence category	How to report
environmental benefit	emissions or curtailment
Measured environmental benefit	Report only where operational monitoring confirms kWh shifted, renewable energy used or emissions avoided
Pending LCA inventory	Identify missing embodied-carbon and end-of-life data

8.4 Resource Efficiency and Circular Economy Aspects

FlexCHESS supports resource efficiency by improving the utilisation of existing DERs, batteries, EV charging assets and flexible loads. Rather than relying only on new infrastructure, the project tests how existing and planned assets can be digitally coordinated through CHESS Nodes and FlexPlatform tools.

The digital twin and CHESS API material is particularly relevant here because it demonstrates a system architecture that can represent assets digitally, monitor status, query submodels and support interoperability through AAS structures, Digital Twin Explorer, UUDEX/RabbitMQ, APIs and CHESS status/capacity interfaces. This supports circular-economy logic because better monitoring and asset visibility can improve maintenance, extend operational life and avoid unnecessary over-sizing.

Resource-efficiency aspects include:

- optimised battery charging and discharging to avoid unnecessary cycling;
- intelligent State of Charge management;
- better use of existing PV, EV charging and HVAC assets;
- improved asset utilisation through aggregation;
- reduced need for redundant infrastructure;
- future potential for second-life EV batteries;
- improved monitoring and maintenance through digital twins;
- better planning of storage sizing through decision-support tools.

For D4.4, these aspects are presented as resource-efficiency pathways rather than confirmed circular-economy outcomes, unless partner evidence on battery degradation, second-life use or recycling is documented.

9 Institutional and Market Readiness

FlexCHESS is designed to test not only technical feasibility, but also institutional and market readiness for distributed flexibility services. Institutional readiness refers to the ability of DSOs, energy communities, utilities, facility managers and technical operators to adopt and operate CHESS-enabled flexibility. Market readiness refers to the ability of FlexCHESS assets and services to participate in flexibility markets, energy communities or future DSO/TSO flexibility procurement mechanisms.

9.1 Regulatory and Policy Compliance

Each pilot operates in a different regulatory and market context. This affects how flexibility can be activated, monetised and scaled.

Pilot	**Institutional / regulatory relevance**
Wales / UK	Simulation-based system learning; useful for industrial flexibility and VESS modelling, but direct market validation is limited unless linked to live UK flexibility markets
Slovenia	Strong DSO relevance; potential for EV smart charging, ADMS/SCADA-linked flexibility and constraint management
Spain	Strong REC relevance; requires attention to energy-community rules, member participation, self-consumption allocation and market access
Italy	Strong commercial-building and utility relevance; requires coordination between building systems, EV charging, PV, BESS and digital platforms
Turkey	Strong island-grid and DSO resilience relevance; flexibility value may be linked more to grid stability than conventional market revenue

9.2 Market Integration Readiness

The uploaded workshop and technical material show that FlexCHESS has a strong platform and simulation basis for market-readiness testing. However, in several pilots, full real-market integration remains a future step.

Market readiness is therefore classified in three levels:

Level	Description	D4.4 treatment
Technical readiness	Assets, data flows, CHESS Nodes, APIs and optimisation logic are available or under deployment	Can be reported as confirmed readiness
Simulated market readiness	Flexibility Market Emulator or scenario testing is used to model market participation	Should be reported as modelled or simulated value
Real market readiness	Actual market participation, bidding, activation and settlement occur	Should only be claimed where partner evidence confirms it

The Italian pilot demonstrates high technical integration complexity and readiness, involving Fox ESS BESS data/control, TLE EV charging data, IREN HVAC/PV data, Aveva Pi, AMU AWS, CHESS Node, FlexPlatform, Azure Digital Twin, UUDEX/RabbitMQ and API Gateway elements.

9.3 Interoperability

Interoperability is one of the strongest institutional-readiness outcomes of FlexCHESS. The project uses CHESS Nodes, adapters, APIs, digital twins, AAS submodels, UUDEX, RabbitMQ, MQTT and cloud-based integration environments to connect heterogeneous assets and data sources.

The IREN deployment specification confirms the use of BESS/EV simulated adapters, HVAC/PV data adapters, FlexPlatform optimisation tools, UUDEX server, RabbitMQ broker, Fox ESS cloud services and Azure Digital Twin APIs.

This supports the conclusion that FlexCHESS is institutionally relevant because it provides a replicable architecture for connecting assets that would otherwise remain technically and organisationally fragmented.

9.4 KER-Based Market Readiness and Exploitation Potential

The KERs provide an additional lens for assessing institutional and market readiness. While pilot performance data demonstrate site-specific readiness, the KERs show which project outputs can be transferred, adapted or further developed after the end of FlexCHESS. This is important because market readiness does not depend only on whether a pilot works technically, but also on whether the resulting tools, services and models can be understood, adopted and financed by future users.

The strongest market-readiness potential is associated with KERs that can be packaged as digital services, APIs, optimisation tools or platform modules. These include real-time digital twins, the distributed HESS energy-management system, forecasting tools, data analytics and machine-learning applications, VESS decision-making tools and the VSoC estimator. These results align closely with the business-model pathways identified in the BMCs, especially SaaS access, API-based services, algorithm licensing, consulting, integration services and performance-based revenue models.

Institutional readiness is also strengthened by the smart-contract KER and the shared VESS knowledge base. Smart contracts can support traceability, transparency and trust in flexibility transactions, while the shared knowledge base can support capacity building, standardisation and replication. These are particularly relevant for DSOs, aggregators, energy communities and policymakers seeking trustworthy and interoperable flexibility solutions.

However, full market readiness remains dependent on regulatory frameworks, access to flexibility markets, cybersecurity requirements, interoperability standards, customer willingness to pay, and the ability of partners to maintain and develop the KERs after the project. Therefore, D4.4 classifies the KERs as exploitable results with strong socio-economic and market potential, while distinguishing between outputs already validated in pilot contexts and outputs requiring further commercial or regulatory development.

10 Cross-Pilot Comparison

The FlexCHESS pilots provide a diverse basis for comparing socio-economic, economic, environmental and institutional readiness across different European contexts.

Pilot	Main value proposition	Strengths	Main constraints
Wales / UK	Simulation-based VESS and industrial flexibility learning	Complex industrial system context; useful for scenario modelling	Limited direct end-user/social acceptance evidence if not live
Slovenia	DSO flexibility, EV smart charging and near-real-time grid support	Strong DSO/system relevance; EV charging and ADMS/SCADA data potential	Requires user participation, data reliability and integration with DSO systems
Spain /	Renewable Energy	Strong community	Market integration

Pilot	Main value proposition	Strengths	Main constraints
Bullas	Community and self-consumption optimisation	value; PV/battery relevance; local participation	and member engagement need validation
Italy / IREN	Multi-building optimisation, EV charging, PV/BESS/HVAC integration	Strong technical-economic value; multiple controllable assets; strong digital twin/adapter evidence	HVAC control, comfort, EV data and integration complexity
Turkey / Gökçeada	Island-grid resilience, renewable integration, load balancing and frequency regulation	Strong environmental and system-resilience value; wind/PV/BESS/EV/heat pump assets	Island-grid complexity, renewable variability, real-time coordination

10.1 Success Factors

Across the pilots, the main success factors are:

- availability of flexible assets such as BESS, EVs, heat pumps, HVAC and flexible loads;
- access to historical or real-time data;
- ability to integrate assets through CHESS Nodes and adapters;
- clear use-case mapping;
- technical workshops aligning pilots with platform capabilities;
- involvement of DSOs, energy communities, utilities and technical partners;
- digital-twin and API-based interoperability;
- clear communication of user and system benefits.

10.2 Common Barriers

Common barriers include:

- incomplete final monitoring data;
- complex integration across SCADA, BMS, EV charging, APIs and cloud systems;
- market-readiness gaps where real markets are not yet connected;

• uncertainty around flexibility revenue;
• user concerns about automation, privacy, comfort and convenience;
• difficulty attributing impacts to FlexCHESS alone;
• different regulatory frameworks across pilot countries.

10.2.1 Comparative Assessment

Assessment dimension	Strongest pilots	Notes
Community acceptance potential	Spain, Turkey	Spain through REC; Turkey through island/community resilience
Commercial optimisation potential	Italy	Strongest multi-asset building/EV/PV/BESS case
DSO system value	Slovenia, Turkey	Strong relevance to grid support and flexibility
Environmental potential	Turkey, Spain, Italy	Wind/PV/storage in Turkey; REC/PV in Spain; PV/BESS/EV in Italy
Interoperability evidence	Italy	Strongest uploaded technical architecture evidence
Simulation/system learning	Wales	Useful for VESS and industrial flexibility modelling

10.3 Replicability and Scalability

FlexCHESS has strong replication potential because it tests a modular and interoperable approach across diverse contexts: industrial simulation, DSO flexibility, renewable energy communities, commercial-building optimisation, EV smart charging and island-grid resilience.

10.3.1 Replication Potential Across EU Contexts

Replication context	Relevant FlexCHESS evidence	Conditions for replication
DSO flexibility	Slovenia, Turkey	Access to grid data, flexibility activation rules, DSO systems integration
Renewable Energy Communities	Spain, Turkey	REC governance, member engagement, PV/storage assets, benefit allocation
Commercial / industrial sites	Italy, Wales	Building-energy data, controllable loads, BESS/EV/PV integration
EV smart charging	Italy, Slovenia, Turkey	EV charging data, user constraints, tariff signals, charging control
Island / constrained grids	Turkey	Local RES, storage, controllable loads, resilience planning
Digital twin / data-space models	Italy	API access, AAS models, digital twin infrastructure, cybersecurity

10.4 Scalability Considerations

Scalability depends on four main dimensions:

- **Technical scalability**

The CHESS Node architecture, adapters, digital twins, APIs and message brokers support modular expansion across additional assets and sites. The digital twin walkthrough demonstrates CHESS adapter, CHESS status, submodel and data specification structures, as well as Digital Twin Explorer and AAS API query/update functions.

- **Economic scalability**

Scaling requires business models that can cover CAPEX, OPEX, software operation, maintenance and flexibility service management. The most viable models are likely to combine subscription fees, pay-as-you-use flexibility services and direct integration/installation packages.

- **Regulatory scalability**

FlexCHESS can scale more easily where flexibility markets, DSO procurement mechanisms, energy-community frameworks and data-sharing rules are clear.

- **Social scalability**

Replication depends on user trust, clear incentives, transparent benefit distribution and simple communication of flexibility concepts.

10.5 Transferability to Non-Pilot Contexts

The main transferable elements are:

• CHESS Node architecture;

• DER onboarding logic;

• forecasting and optimisation workflows;

• digital twin / AAS / API structures;

• smart EV charging strategies;

• REC management and self-consumption optimisation logic;

• DSO flexibility and grid-support use cases;

• socio-economic assessment framework and T4.3 survey method.

The main non-transferable elements are site-specific: local regulation, tariffs, grid constraints, available assets, stakeholder readiness and market access.

10.6 KERs as Replication Assets

The FlexCHESS KERs should be considered replication assets because they provide transferable tools, methods and service concepts that can be adapted beyond the original pilot sites. Unlike site-specific pilot infrastructure, KERs such as digital twins, forecasting systems, data analytics, VESS decision-making, smart contracts and knowledge bases can be reused across different energy contexts, provided that local data, market rules and stakeholder requirements are addressed.

KER / Exploitable Asset	Replication potential	Main replication conditions
Real-time digital twins	High	Requires asset data, interoperability standards, API access and cybersecurity framework.
Energy management system for distributed HESS	High	Requires controllable assets, optimisation goals and integration with site or grid systems.
VESS concept and VSoC estimator	Medium-High	Requires aggregated distributed resources and reliable estimation of

		available power/energy capacity.
CHESS-plug	Medium-High	Requires user-side devices, data-collection infrastructure and acceptance of smart control.
ML/data analytics for HESSs	High	Requires historical/real-time data and adaptation to local energy behaviour.
Decision-making tools for VESSs	Medium-High	Requires flexibility indicators, eligibility logic and market/grid-service rules.
Smart contracts for VESSs	Medium	Requires regulatory acceptance, transaction rules and blockchain/smart-contract governance.
Forecasting system	High	Requires weather, production, consumption and market data.
Shared VESS knowledge base	High	Requires partner/user contribution, maintenance and standardisation.

These KERs support replication because they reduce the need to rebuild the FlexCHESS logic from the beginning in every new context. Instead, future adopters can adapt existing digital tools, data models, optimisation approaches, knowledge structures and business models to new DSOs, RECs, commercial buildings, EV charging communities, industrial sites or island grids.

11 Policy Recommendations

11.1 For EU-Level Policymakers

1. **Harmonise flexibility market frameworks across Member States.**
2. FlexCHESS shows that flexibility services require interoperability not only at technical level, but also at market and regulatory level. Different rules across countries can limit replication.
3. **Support DSO flexibility procurement as an alternative to conventional reinforcement.**
4. DSO-led pilots such as Slovenia and Turkey show the value of flexibility for congestion management, load balancing, frequency support and resilience.
5. **Clarify data governance for energy communities and flexibility services.**

6. Smart metres, EV charging, digital twins and automated control require clear data access, consent, privacy and cybersecurity rules.
7. **Promote interoperability standards and digital-twin approaches.**
8. EU policy should support standardised APIs, AAS models, data spaces and interoperable asset descriptions to avoid vendor lock-in.
9. **Support energy communities as flexibility actors.**
10. The Spanish and Turkish pilots demonstrate that RECs and island communities can contribute to flexibility and renewable integration if rules and incentives are clear.

11.2 For National and Regional Authorities

1. **Introduce technology-neutral flexibility tenders.**
2. Flexibility procurement should allow batteries, EVs, heat pumps, HVAC, PV and aggregated DERs to participate.
3. **Establish fair compensation mechanisms.**
4. Users, prosumers and communities should see clear benefits from participating in flexibility mechanisms.
5. **Support pilot-to-policy feedback loops.**
6. National authorities should use Horizon Europe pilot evidence to identify regulatory bottlenecks and update flexibility frameworks.
7. **Fund capacity-building for DSOs, municipalities and energy communities.**
8. Flexibility requires technical, legal and organisational skills that are not yet equally available across Europe.
9. **Encourage transparent self-consumption and benefit-sharing models.**
10. This is particularly important for RECs and community-scale pilots.

11.3 For Distribution System Operators

1. **Adopt open APIs and interoperable data standards.**
2. DSOs should avoid closed systems that prevent aggregation of distributed flexibility.
3. **Publish granular network constraint and flexibility-need data.**
4. Flexibility can only be valued if system needs are visible and actionable.
5. **Develop DSO–aggregator collaboration frameworks.**
6. CHESS-enabled flexibility depends on collaboration between asset owners, aggregators, platform operators and DSOs.
7. **Enable smart EV charging as a flexibility resource.**
8. EV charging should be treated as a controllable, user-sensitive resource that can reduce grid stress when managed transparently.
9. **Use digital twins and simulation to support planning.**
10. Digital-twin approaches can help DSOs test scenarios, understand asset behaviour and plan flexibility procurement.

In addition, policymakers and funding bodies should support the post-project exploitation of validated digital-energy KERs. FlexCHESS demonstrates that flexibility-market development requires not only physical assets, but also digital twins, forecasting systems, interoperable APIs, decision-support tools, smart contracts, shared knowledge bases and viable business models. Future policy instruments should therefore support the transition of such KERs from pilot validation to deployment, including through regulatory sandboxes, standardisation support, interoperability requirements, cybersecurity certification, and incentives for DSOs, aggregators and energy communities to adopt digital flexibility tools.

12 Conclusion

This deliverable has presented a socio-economic, economic and environmental assessment of the FlexCHESS pilots, conducted under Task 4.3 and led by Citizens in Power (CIP), with input from the wider consortium and supporting evidence from WP4, D4.2, pilot workshop material, digital twin documentation and the T4.3 survey framework.

The assessment demonstrates that FlexCHESS provides a credible pathway for turning distributed energy resources into coordinated flexibility assets. Across the five pilot contexts, the project shows how batteries, EV charging, PV, wind, heat pumps, HVAC systems, industrial loads, energy communities and DSO systems can be connected through CHESS Nodes, FlexPlatform tools, digital twins and interoperable data architectures.

12.1 Key Findings

Socio-economic impacts

FlexCHESS is expected to generate positive socio-economic value where stakeholders understand the benefits of flexibility, trust the data governance model and receive clear incentives. The strongest community relevance is found in Spain and Turkey, while Italy and Slovenia show strong operational and institutional value.

Economic viability

The strongest economic cases are those that combine multiple value streams: energy-cost optimisation, peak shaving, load shifting, PV self-consumption, EV smart charging, flexibility-service potential and avoided system costs. Italy and Spain show strong near-term business-model potential, while Slovenia and Turkey provide strong DSO/system-value cases.

Environmental benefits

FlexCHESS can support environmental goals by increasing renewable-energy utilisation, reducing curtailment potential, improving storage use, optimising EV charging and reducing peak-related grid stress. Final emissions and curtailment values require pilot monitoring and LCA inventory data.

Institutional and market readiness

FlexCHESS has strong technical readiness in terms of interoperability, digital twins, APIs, CHESS Nodes and platform architecture. Market readiness varies by pilot and should distinguish between simulated flexibility-market value and actual market participation.

12.2 Main Contributions

The main contributions of D4.4 are:

- a multi-dimensional assessment combining S-LCA-informed analysis, cost-effectiveness logic, LCCA principles and environmental screening;
- a cross-pilot comparison of five European contexts;
- a structured methodology for distinguishing measured, modelled, partner-reported and validation-stage impact evidence;
- identification of socio-economic barriers and enablers;
- policy recommendations to support flexibility-market development and replication;
- a T4.3 stakeholder-engagement framework for validating social acceptance, perceived benefits and barriers.

12.3 Limitations and Future Work

This assessment is based on evidence available at the M36 cut-off; subsequent reporting will incorporate consolidated partner monitoring and validation data as it becomes available.

Nevertheless, the evidence available demonstrates that FlexCHESS has strong potential to support Europe's energy transition by making distributed assets more flexible, interoperable, socially useful and environmentally relevant.

13 References

The reference list includes the project deliverables and internal evidence used throughout D4.4. Based on the uploaded material, the following references are included:

1. **FlexCHESS Grant Agreement No. 101096946**, Horizon Europe Research and Innovation Action.
2. **D4.2 – The Optimal Adaptation of DERs within FlexCHESS and the Key Requirements of Efficient Deployment of FlexCHESS Nodes**, Cardiff University, Final Version.
3. **D4.3 – Report on Pilot Sites Results**, UEDAŞ, Final Version, May 2026.
4. **D1.5 – Use Case Definition and Scenario Mapping**.
5. **D1.3 – KPI Framework / Technical and Functional KPI Definitions**.

6. **D5.5 – Business Model Assessment**.
7. **FlexCHESS Italian Pilot Site Workshop – IREN Multi-Buildings, Torino**.
8. **FlexCHESS Spanish Pilot Site Workshop – Bullas Renewable Energy Community**.
9. **FlexCHESS Turkish Pilot Site Workshop – Gökçeada Island Energy Community**.
10. **FlexCHESS Slovenian Pilot / WP4 Demonstration and Validation Update**.
11. Socio-Economic and Environmental Assessment.
12. **FlexCHESS CHESS Digital Twin Guide**.
13. **FlexCHESS Digital Twin Walkthrough Presentation**.
14. **T4.3 Socio-Economic Impact Survey Instrument**.
15. UNEP, **Guidelines for Social Life Cycle Assessment of Products and Organisations**, 2020.
16. UNEP, **Methodological Sheets for Subcategories in Social Life Cycle Assessment (S-LCA)**, United Nations Environment Programme / Life Cycle Initiative, 2021.
17. GreenDelta, **PSILCA – A Product Social Impact Life Cycle Assessment Database** (Database version 3.1, Documentation version 1.2), 2023.
18. ISO 14040:2006, **Environmental Management – Life Cycle Assessment – Principles and Framework**.
19. ISO 14044:2006, **Environmental Management – Life Cycle Assessment – Requirements and Guidelines**.

List of KERs according to Grant Agreement – FlexCHESS Key Exploitable Results, partner ownership, WP allocation, TRL progression and expected improvements.
FlexCHESS KER Data Collection Files – AMU, CU, RDIUP, Arcelik, Toshiba and UniGe partner inputs.
FlexCHESS Business Model Canvas Evidence – AMU, Arcelik, Cardiff University, Elektro Ljubljana, IREN, MIW/LaSolar, Toshiba, UEDAS and RDIUP EVYLOR/Skycamera BMC files.
Business Model Canvas – Strategyzer template used for partner exploitation mapping.

14 Annexes

14.1 Annex 1: Ethics & Data Protection

All socio-economic data collected under Task 4.3 complies with GDPR and ethical research standards. Participation is voluntary, based on informed consent, and data is anonymised. No sensitive personal data is collected. Data is used solely for research, reporting and policy analysis purposes. Participants may withdraw at any time without consequences.

16.2 Annex 2: Evidence Classification Matrix

Evidence Type	Definition	How Used in D4.4
Confirmed documentary evidence	Information directly available in D1.1–D1.5, D4.2, D4.3, D5.5, workshop files, technical guides and survey documentation	Used to describe concepts, use cases, assets, data streams, platform capabilities and readiness
Partner-reported/survey evidence	Responses from T4.3 survey, partner data tables or interviews	To validate satisfaction, acceptance, behaviour change and pilot-specific impact

16.3 Annex 3: KER and Exploitation Evidence Matrix

Evidence type	**Source**	**Use in D4.4**
GA-listed KERs	List of KERs according to GA	Used to identify exploitable project outputs, TRL progression and expected improvements.
Partner KER data collection files	AMU, CU, RDIUP, Arcelik, Toshiba, UniGe KER data sheets	Used to support partner-level exploitation mapping and future KER validation.
Business Model Canvas files	AMU, Arcelik, CU, EL, IREN, MIW/LaSolar, Toshiba, UEDAS, RDIUP EVYLOR and Skycamera BMCs	Used to identify value propositions, customer segments, revenue streams, cost structures and market pathways.
D5.5 Incentive-based Business Model	D5.5	Used to connect KERs to market analysis, business-model viability, SWOT/PESTEL logic and exploitation planning.
T4.3 Survey / Socio-economic framework	T4.3 survey documentation	Used to connect KERs with social acceptance, perceived benefits, barriers and stakeholder value.

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