Collective Intelligence for Energy Flexibility – COLLECTiEF: An EU H2020 Project for Enhancing Energy Efficiency and Flexibility in Existing Buildings

2023 International Conference on Future Energy Solutions (FES) | 979-8-3503-3230-8/23/$31.00 ©2023 IEEE | DOI: 10.1109/FES57669.2023.10182779

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***Abstract*—COLLECTiEF (Collective Intelligence for Energy Flexibility) is an EU-funded H2020 project running from June 2021 to May 2025. COLLECTiEF aims to enhance, implement, test, and evaluate an interoperable and saleable energy management system based on collective intelligence that allows easy and seamless integration of legacy equipment into a collaborative network within and between existing buildings and urban energy systems with reduced installation cost, data transfer, and computational power while increasing user comfort, energy flexibility, climate resilience, and data security. To achieve this goal, the COLLECTiEF solution requires the development of software and hardware packages to smart up buildings and their legacy equipment on a large scale while maintaining simple and robust communication with the energy grid. Here, we present the project concept, structure, objectives, and working packages. Furthermore, the main progress and achievements obtained during the first two years of the project are presented.**

Keywords— COLLECTiEF, Collective intelligence, Energy flexibility, Climate resilience, Urban energy system, Demand side management

I. INTRODUCTION

The European Union (EU) has been at the forehand of international efforts to tackle the global challenge of climate change and emissions of carbon dioxide (CO_2) impacts, and to deploy affordable, reliable, and modern energy services as well as to increase the share of renewable energy, according to the Sustainable Development Goals no. 7 and 13 [1], [2]. Rapid urbanization is exacerbating energy consumption in urban areas [3]. Building and construction sector is responsible for approximately 65% of global primary energy consumption, making them the largest single energy consumer [4], [5]. Improving energy performance in buildings can contribute significantly to achieving the energy and climate goals since the urban areas play a crucial role in the energy transition and the path towards sustainability.

To this end, it is crucial to search for strategies and technological solutions that reduce energy use and to cover the remaining energy demand through sustainable approaches such as increasing the penetration of variable renewable energy (VRE) [5]–[7]. Both VRE and urban energy demand are highly affected by climate conditions, causing a mismatch in demand and generation profiles [8], [9]. Enhancing the energy flexibility on both supply and demand sides can boost the movement towards sustainable and resilient urban energy solutions [9], [10].

The demand flexibility of buildings can become a major source of energy flexibility since buildings account for a large proportion of energy consumption [11]. However, buildings with flexible loads work best if they are connected into a cluster that responds to the grid signal. In addition, larger buildings normally have a higher level of building automation coming from legacy equipment than small homes. Thus, creating a system that allows up-smarting the legacy equipment for larger buildings will have a greater impact than conventional smart home approaches targeting private homeowners.

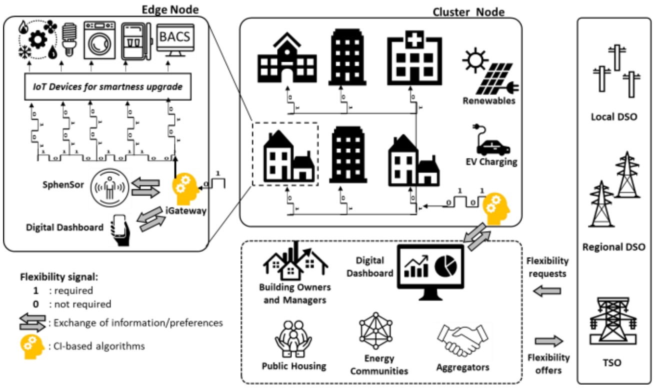

Fig. 1. The conceptual design of the COLLECTiEF project

The Collective Intelligence for Energy Flexibility (COLLECTiEF) project aims to develop an energy management (EM) system based on Collective Intelligence (CI) that allows easy and seamless integration of legacy equipment into a collaborative network within and between existing buildings and urban energy systems. Fig. 1 depicts the conceptual design of the COLLECTiEF project. The main objectives and contributions of the COLLECTiEF project are summarized as follows:

1. Enhancement and adaptation of algorithms for creating a CI-based energy-flexible network,

2. Realization of CI-based cost-effective system components with easy deployment and maintenance,

3. Demonstration and testing of a CI-based energy network in the real environment,

4. Testing and implementing a scalable and customizable occupant-centric fusion sensor network for accurate and non-invasive environmental monitoring,

5. Designing and implementing a smart, user-centric, and user-friendly digital platform for interacting with users and controlling technical building systems,

6. New business model for energy services, including a clear model for commercialization of the COLLECTiEF system.

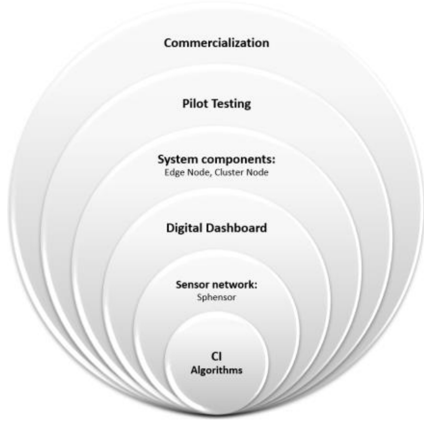

Fig. 2. The objectives relations in the COLLECTiEF project

The main core of the COLLECTiEF project is shaped around enhancing the existing CI algorithm [5] and developing it further to address the complex interactions between buildings at the urban scale and to generate optimum control strategies at the building and cluster levels. The CI algorithm (Obj.1) will shape the design of the sensor network (Obj.4), the user inputs/interactions and the digital dashboards (Obj.5), and the system components at the edge and cluster nodes (Obj.2). The solutions will be tested in the pilots and ameliorated during the demonstration phase (Obj.3). The final goal is to have the system qualified (TRL8) and ready for commercialization with a new business model (Obj.6). Objective's relations are depicted in Fig. 2.

II. Method and Implementation

COLLECTiEF implements and evaluates an interoperable and saleable EM system based on Collective Intelligence (CI). The concept of CI connects the following three pillars in the COLLECTiEF project: (1) Resilience, demand-response, and energy flexibility on the level of multiple buildings; (2) Smart buildings and smart components; (3) Occupant-centric operation.

A. *Methodology*

COLLECTiEF develops software and hardware packages to smart up buildings of different typologies common in Europe and their legacy equipment, sort out consumer-centric and industry-centric challenges, and maintain simple and robust communication with the energy grid. The simple communication acts as a stimulus to help buildings sense the grid's need for flexibility and accordingly within the limits of their local constraints and users' preferences. The overall methodology of the project includes the following steps and approaches: (1) Development of control strategies, algorithms, and frameworks for demand side management; (2) Adaptation of the technical components to the use case; (3) Evaluation of the COLLECTiEF algorithms and control strategies as well as the complete COLLECTiEF solutions on the District MOdeller and SIMulator (DIMOSIM) platform [12]; (4) Testing in a small-scale demonstration site; (5) large-scale demonstration of the COLLECTiEF solutions in 13 pilot buildings located in three countries namely, Norway, Italy, and Cyprus; (6) Development of business models and exploitation of the results; (7) Capacity building and stakeholder engagement. Fig. 3 shows the value chain of COLLECTiEF and the involved partners in each stage.

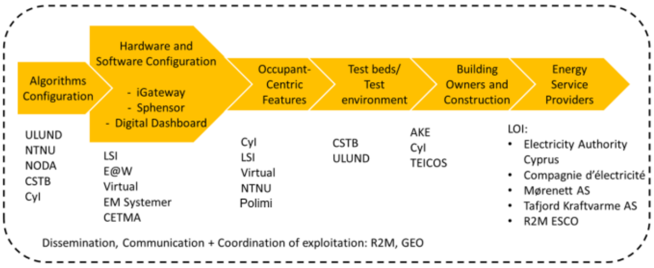

Fig. 3. The COLLECTiEF value chain

B. Implementation and work packages

The COLLECTiEF consortium consists of 15 beneficiaries from universities, institutions, manufacturing and construction companies, and municipal sectors from six countries across Europe. COLLECTiEF comprises seven work packages (Fig. 4) aligned with each other which aim at developing, implementing, testing, and evaluating the proposed EM system based on CI.

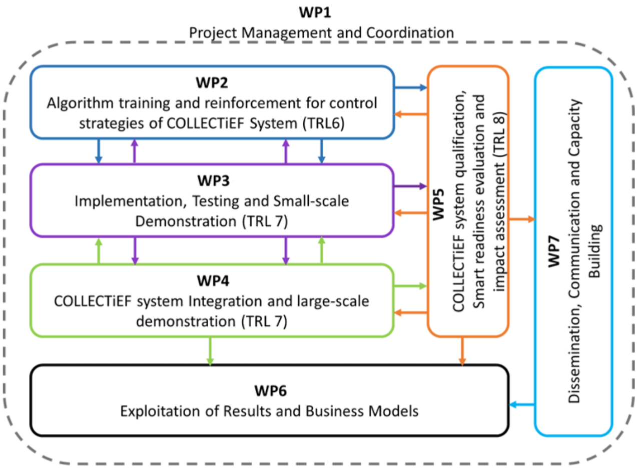

Fig. 4. The overview of work packages in the COLLECTiEF project

WP1 coordinates the COLLECTiEF project management and administration as well as supervises the activities carried out by all partners with defined tasks and according to the Grant Agreement and planned action plan. WP2 focuses on the development of algorithms and communication logic of the COLLECTiEF EM system. The partners are developing, testing and enhancing existing and new solutions using a virtual test bed, DIMOSIM [12], and in a real environment at the G2Elab. WP3 aims at developing and implementing the prototype of the COLLECTiEF network, including hardware and software technologies for demonstration in a real small-scale environment in the G2Elab. WP4 focuses on the Edge Node, Cluster Node, occupant-centric fusion sensor network, IoT Operating System, and Human-Building interface. WP4 has worked on the template for identifying user parameters and will adapt it to COLLECTiEF requirements. WP5 deals with the definition of the measurement and verification protocol and the evaluation of the impacts given by the implementation of the COLLECTiEF solutions on building smartness, energy saving and flexibility, indoor environmental quality, and climate resilience. WP5 interfaces with all the work packages for the eventual completion and qualification of the COLLECTiEF system at TRL 8. WP6 aims to carry out an effective exploitation process of the project results, emphasizing results with commercial and industrial exploitation potential. For this, all COLLECTiEF partners are involved. Finally, WP7 focuses on the project's proper visibility and spreads pertinent information on its goals, activities, and results to the relevant stakeholders and scientific communities, thereby fostering the engagement of the target audience including end users and stakeholders in the COLLECTiEF activities.

C. Project structure

COLLECTiEF project originates from the identification of available knowledge and technologies within the consortium that have been validated and demonstrated in previous projects and which fall under the technology readiness level (TRL) 5 or 6. These technologies allow the creation of a complete CI-based energy network and within the 4-year timeline of the project, the main aim is to qualify the COLLECTiEF solutions in four real applications, hereafter called "DEMO", which will bring the overall TRL to 8. Therefore, project management is divided into two main phases, namely (1) before the start of the DEMO, (2) after the start of the DEMO.

This classification aims at organizing and monitoring the defined tasks as well as at providing a better overview of the project's progress. The main activities are summarized in Table I.

TABLE I. THE MAIN ACTIVITIES AND MILESTONES

Before the Start of the DEMO (M1-M24)	**After the Start of the DEMO (M24-M48)**
Definition of the Measurement and Verification Protocol completed	Testing in small-scale test bed completed
Involvement of the users and occupants of the pilot buildings conducted	Demonstration phase in large-scale completed
Project communication kit developed	Involvement of the users and occupants of the pilot buildings
Data management plan	Stakeholder workshops conducted
Control algorithms ready for testing	Business model defined, showing commercial feasibility
Edge Node, Cluster Node, human-building interface, and occupant-centric sensor network ready for testing	Capacity training material ready for use
Installation in pilots completed	Evaluation of the impacts. System complete and qualified (TRL8)
Market Analysis (Stakeholder and competitors analysis, Regulatory framework, market environment research) completed	Project completed

III. PROJECT PROGRESS AND ACHIEVEMENT

A. Activities performed and objectives progress

The COLLECTiEF consortium performed numerous dedicated tasks and planned activities as well as obtained several achievements according to milestones and action plan by month 24. Additionally, the WPs and Tasks leaders submitted up to 22 deliverables to EU Commission by month 24. The main developments and achievements are described as follows:

The first version of the EM algorithms at the building (Edge node) and cluster (Cluster Node) levels has been developed based on combining COLLECTiEF Intelligence and Reinforcement Learning with promising results. The algorithms are being fine-tuned to be implemented at the edge and cluster nodes. The major indicators in developing the algorithms have been energy demand and indoor thermal comfort so far. Depending on the need, the indicators and objectives will be updated in future versions of the algorithms. Representative weather data sets have been generated considering several future climate scenarios. The weather data sets have been used in running the algorithms and setting the control strategies to assess their impact in adapting to climate variations and decreasing energy demand while guaranteeing adequate indoor thermal comfort conditions for occupants. Different approaches for modelling and assessing indoor thermal comfort have been developed, which will be integrated further into the control algorithms. Moreover, the algorithms are being developed to include other factors/indicators, such as energy price. A functioning platform for data sharing and integration, algorithm development, and co-simulation has been created in GitHub, to which all the relevant users have access. The virtual test bed using DIMOSIM for algorithms and controls has been developed and tested at G2ELab. Fig. 5 demonstrates the schematic diagram of the implementation of algorithm. The flowchart of the code is presented on top right of the figure. The G2ELab's dashboard is used to visualize the data (i.e. sensor and actuator values) in real-time.

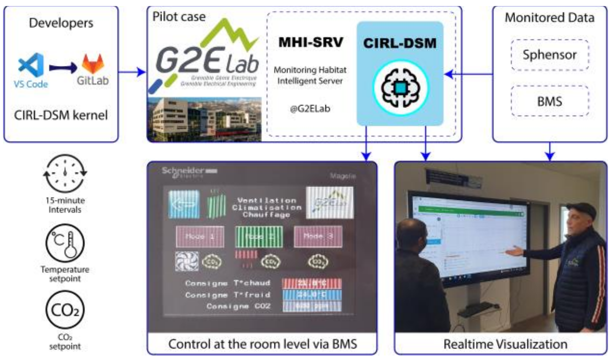

Fig. 5. Workflow of the small-scale test in G2ELab. bottom-left: BMS panel in the rooms, top-right: flowchart of the developed algorithm, bottom-right: real-time visualization platform to demonstrate the performance of the code.

The Border Router has been adapted on the Raspberry Pi 4 open board to have a platform capable of supporting the computational load foreseen by the project. In addition, the legacy and already-in-place devices in the different pilot buildings were investigated, and the smart devices for interfacing with the field, such as smart plugs and smart thermostats, have been identified. Significant steps forward have been made to achieve this goal, mainly from the hardware point of view. Particularly, the reference open board (Raspberry Pi 4), capable of integrating the edge computing functions envisaged by the project, has been selected based on which the entire hardware platform of the Edge node-BRiG (Border Router + iGateway) was built. The specifications for the use of Raspberry Pi 4 were defined, and the porting of the Border Router firmware (previously based on the less-performing BeagleBone open board) on Raspberry Pi 4 was implemented. The electronic schematic and PCB of BRiG were developed in this first period. Afterward, based on them, the different components were mounted on the BRiG prototypes and subsequently functionally tested.

A Measurement & Verification (M&V) plan has been defined to evaluate the implementation of the COLLECTiEF solutions targeting not only energy savings and indoor environmental quality (IEQ) but also including the methods to measure and verify the load reduction and management improvement, resulting from the utilization of energy flexibility strategies, and the enhanced climate resilience. The Deliverable D5.1 - Performance Measurement & Verification Protocol – concepts and methods for performance evaluation of COLLECTiEF solutions describes the process of M&V in COLLECTiEF, presents the methodology, and the key performance indicators (KPI) selected to assess the impacts on the smart readiness of buildings, energy performance, indoor environmental quality, energy flexibility, and climate resilience. Furthermore, Deliverable D5.2 – Ongoing performance evaluation of the COLLECTiEF system implemented in the pilot cases presents in detail the methodologies to assess the indoor environmental quality in the buildings and shows the progress on the monitoring and preliminary analysis of the data collected in the pilot buildings (see Fig. 6), pointing out lessons learnt and mitigation strategies.

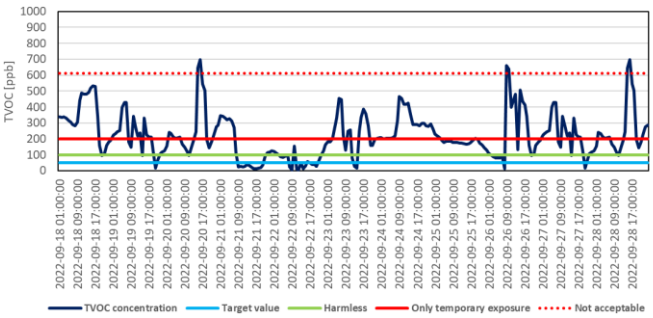

Fig. 6. Example of data representation regarding TVOC concentration in one of the monitored pilot buildings

The smart-ready technologies (e.g., smart meters, smart thermostats, sensors, and IoT devices) to be installed in the different pilot buildings have been selected, and it has been initiated the activities related to the development of communication, development, and testing in simulated environments of the algorithms able to connect to the use of digital technologies, and the algorithms for energy, comfort optimization, and flexibility management are guaranteeing the protection of privacy and security of smart buildings.

We finalized the implementation of the occupant-centric fusion sensor network in the pilot buildings. For most parts, the implementation has been successful, and the communication between the sensors and the BRiG device is operational and running. The sensor placement has been executed in a manner that minimizes interference with the user environment, while effectively characterizing the indoor environments see Fig. 7.

Fig. 7. Picture of the installed IEQ monitoring system and Post Occupancy Evaluation QR code in one of the pilot buildings in Norway

Fig. 8. Picture of the installed IEQ monitoring system and Post Occupancy Evaluation QR code in one of the pilot buildings in Norway. The concept and architecture of the Human-Building Interface were defined and described in Deliverable D3.8: Fully Integrated Dashboard for Cluster Node and Human-Building Interface for the Edge Node (first version). Moreover, the prototype has been developed by including different functions, data insights, and authentication mechanisms.

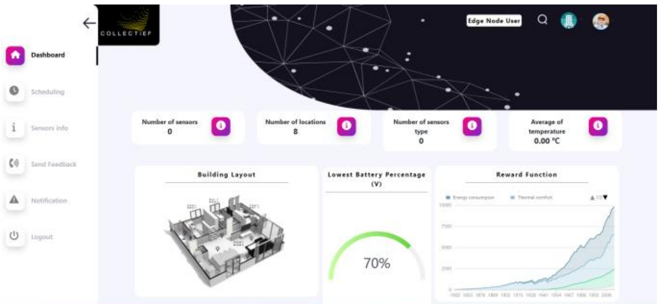

Fig. 8. The COLLECTiEF's Human-Building Interface homepage

Besides, the development of the Human-Building Interface is under further development, see Fig. 7. The comprehensive market analysis has been finalized, providing a foundation for the development of business models that can meet the market requirements for the effective exploitation of the COLLECTiEF solutions. Particularly, R2M provided the analysis of the contexts where the business models operate through a PESTLE analysis (see Fig. 9) and the assessment of the market readiness across various EU countries. Additionally, the analysis also included evaluations of successful examples and potential competitors in the COLLECTiEF market space, highlighting their main functionalities, provided services, commercialization strategies, and adopted business models. This information is valuable for benchmarking and serves as a reference point for developing business models for exploiting COLLECTiEF solutions. Further discussions have been carried out to guide the development of the business.

From the beginning of the project, we have been actively engaged in efforts to enhance the visibility of the project. Regarding dissemination, first, the visual identity was designed. It was followed by the launch of the website. A set of materials such as leaflets, rollups, banners, and posters were created. A stakeholder database was set up for the partners to mobilize their network.

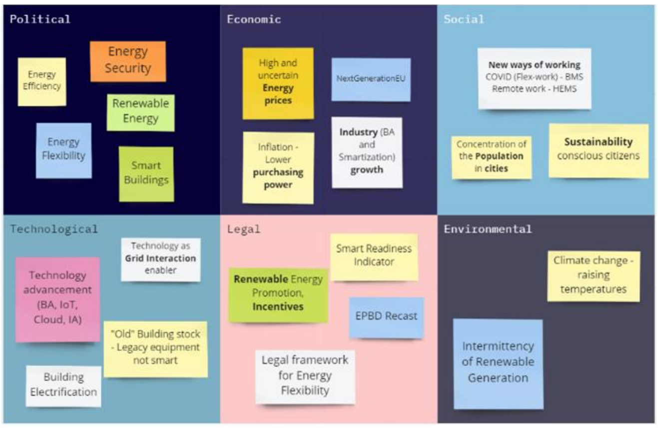

Fig. 9. PESTLE analysis (main topics covered)

When it comes to the engagement with the pilot sites, the first workshops were held physically in Milan, Italy, and in Ålesund, Norway. Social media accounts on popular platforms such as Twitter, LinkedIn, and YouTube were launched. As of M12, WP7 started to publish a newsletter within the networking activities. In addition, the COLLECTiEF project first collaborated with the SMART2B project and then with three additional Horizon2020 projects, creating a cluster called EU4BET. EU4BET participates in the Horizon Results Booster service. As part of the capacity building and sustainability actions, the project joined forces with the SmartBuilt4EU project and participated in the workshop about Smart Buildings in Nice, France.

B. *Expected impacts and progress*

The COLLECTIEF project foresees different impacts in relation to the various domains which are affected by the system implementation (building smartness, energy, indoor environmental quality, climate flexibility and resilience). In particular, the project aims to reach the following six main results:

- Impact 1: Upgrade existing buildings to higher smartness levels

The COLLECTiEF system aims at upgrading the existing pilot buildings with at least one level of smartness according to Smart Readiness Indicator (SRI) scoring methods, independently from the starting smart readiness level. The assessment of the smartness level requires carrying out visual inspections of the pilots and collecting technical data and information. The SRI is calculated in each pilot building before and after the implementation of the systems.

- Impact 2: Reduction in energy consumption and costs

Depending on the building's thermal quality and climate zone, 9-27% relative energy reduction is estimated for buildings after installation of the COLLECTiEF system and upgrading by one level of smartness. The assessment will be carried out in a hybrid way: (1) by the use of measurement of energy consumption and environmental variables (i.e. independent variables such as weather) at the pilot buildings and, thus limited to the boundary of the selected apartments/rooms. (2) By the use of calibrated models of the pilot sites on which the COLLECTiEF algorithms will apply their optimized operation. This will allow extending the impact assessment from the zone to the building/cluster of buildings level. Further, energy cost savings will be evaluated.

- Impact 3: Primary Energy Savings triggered by the project (in GWh/year)

An average of 16% reduction in primary energy use of the pilot buildings, equivalent to 0.93 (GWh/year), is estimated after the implementation of the COLLECTiEF systems. For the evaluation of primary energy savings, updated primary energy factors (PEF) will be considered.

- Impact 4: Investments in sustainable energy triggered by the project (in million EUR)

The implementation of the COLLECTiEF system is expected to generate up to a 52% increase in the self-consumption rate. Among the 14 pilot buildings, only two buildings include renewable energy production from photovoltaics systems. Thus, to get a broader view of the potential impact of increasing self-consumption, some calibrated pilot building models will be virtually equipped with REN energy systems.

- Additional Impact 5: User satisfaction

The project aims at increasing user satisfaction with respect to some of the components of the indoor physical environment by at least 15%, thanks to the implementation of smart occupant-centric sensoring and self-learning control algorithms. User satisfaction will be assessed through two questionnaires: (i) the Post-Occupancy Evaluation (POE) questionnaire and (ii) the Satisfaction questionnaire, that aim to acquire information about occupant's perception of living conditions and to collect data about their satisfaction. A comparison will be conducted between the baseline period, where no control action has been taken on the pilot buildings, and the implementation period, where the COLLECTiEF system will be applied.

- Additional Impact 6: Increased climate flexibility and resilience in urban areas, inducing larger integration of renewable generation.

Fluctuations in the energy demand are greatly influenced on climate variations, particularly during extreme climate events. Climate change can exacerbate this situation by causing more frequent and severe extreme weather events. This results, for example, in having more frequent heatwaves and cold snaps. Supplying enough energy for such times is challenging, since the demand profiles change significantly with considerable loads on the supply system. With the energy management approach that is suggested in COLLECTiEF, it is possible to pass these extreme conditions safely since the COLLECTiEF system enables enhancing the energy flexibility in the network through a collaborative response of buildings and energy systems to climate shocks, resulting in improved climate resilience in urban areas.

IV. Conclusion

COLLECTiEF is an EU-funded H2020 project, running for 4 years – from 2021 to 2025. COLLECTiEF aims to enhance, implement, test, and evaluate an interoperable and saleable energy management system based on CI that allows easy and seamless integration of legacy equipment into a collaborative network within and between existing buildings and urban energy systems with reduced installation cost, data transfer, and computational power while increasing data security, energy flexibility and climate resilience.

COLLECTiEF project commits addressing reliable and practical solutions for the challenges of climate change impacts and renewable energy penetration by enhancing the energy flexibility and climate resilience through a collective intelligence (CI) approach.

The COLLECTiEF consortium performed numerous dedicated tasks and planned activities as well as obtained several achievements according to COLLECTiEF's milestones and action plan by month 24. Furthermore, COLLECTiEF's partners submitted up to 22 deliverables to EU Commission by month 24.

During the next two years, the COLLECTiEF consortium will focus on further developing the software/hardware and initiating the large-scale demonstration as well as testing and qualifying COLLECTiEF's solutions. We will also work on the business model and the exploitation plan in order to roll up the commercialization after completing the project.

Acknowledgment

COLLECTiEF project has received research funding from European Union's H2020 research and innovation programme under Grant Agreement No 101033683.

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