D5.3. Report including market solutions and business models to enable the growth and sustainability of distributed EES

WP5 – Green economy models and Management Systems

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List of abbreviations

BEN	Beneficiary
BESS	Battery Energy Storage System
BMC	Business Model Canvas
BMs	Business Models
CAPEX	Capital Expenditure
CES	Community Energy Storage
CNR	Consiglio Nazionale delle Ricerche
COE	Cost of Energy
DERs	Distributed Energy Resources
D5.3	Deliverable 5.3
DoA	Description of Action
DRL	Deep Reinforcement Learning
DS	Doctoral School
ECs	Energy Communities
ECPE	European Center for Power Electronics
EES	Electrical Energy Systems
EMS	Energy Management System
ESR	Early-Stage Researcher
ESS	Energy Storage Systems
ETN	European Training Network
EU	European Union
EVCS	Electric Vehicle Charging Stations
FIFO	First in First Out
FLC	Fuzzy Logic Control
FS	First Scenario
GA	Genetic Algorithm
GAMS	General Algebraic Modelling System
GDPR	General Data Protection Regulation
GHG	Greenhouse Gas Emissions
ICE	Internal Combustion Engine
IEMD	Internal Energy Market Directive
IRP	Individual Research Project
ITN	Innovative Training Network
LCF	Lean Canvas Framework
LSTM	Long Short-Term Memory
MILP	Mixed Integer Linear Program
MLP	Multilevel Perspective
MSCA	Marie Sklodowska-Curie Actions
NPC	Net Present Cost
OPEX	Operational Expenditure
P2P	Peer-to-Peer
PC	Project Coordinator
PV	Photovoltaic
REC	Research Ethics Committee
RED	Renewable Energy Directive
RES	Renewable Energy Source
RNN	Recurrent Neural Network
RSC	Recruitment and Secondment Committee
SIEM	Siemens
SMEs	Small and Medium Enterprises
SNM	Strategic Niche Management
SOC	State of Charge
SS	Second Scenario
TOA	Time of Arrival
TOD	Time of Departure
TS	Third Scenario
UB	Università Bocconi

UNL	Universidade Nova de Lisboa
V2G	Vehicle to the Grid
V2H	Vehicle to Home
VPP	Virtual Power Plants
WP5.3	Work Package 5.3
WT	Wind Turbines
ZCMES	Zero-Carbon Multi-Energy System

1. Executive summary

Work Package 5 (WP5) focuses on coordinating research and supporting the development and application of business models for collaborative renewable energy systems, microgrids, and energy management. This deliverable builds on the research conducted by ESR14 and ESR15, which enhances the understanding of market solutions and business models that can enable the growth and long-term sustainability of distributed electrical energy systems (EES). The outcomes are also relevant to the technological advancements achieved under WP2, WP3, and WP4.

Within this context, both ESR14 and ESR15 concentrated their work on the concept of Energy Communities (ECs). The European Union recognizes ECs as legal entities designed to facilitate the energy transition toward a more sustainable system, as defined in two legislative frameworks: the Renewable Energy Directive (RED II – EU 2018/2001), which establishes Renewable Energy Communities, and the Internal Energy Market Directive (IEMD – EU 2019/944), which establishes Citizen Energy Communities. Despite their differences, both directives share the objective of empowering local actors—such as citizens, small and medium enterprises, and municipalities—to actively participate in the production, consumption, and management of energy. In this way, ECs contribute to democratizing energy management and can engage across the energy value chain, providing a wide range of services including self-consumption, flexibility to the grid, and the operation of electric vehicle charging infrastructure.

In order to advance the objectives of WP5, ESR15 carried out a bibliometric literature review on Energy Communities. This review provided a comprehensive mapping of the academic research in the field, identified the progress achieved to date, and revealed existing gaps that are relevant for further inquiry. One of the main gaps concerns the understanding and categorization of business models (BMs) for ECs. To address this, ESR15, in collaboration with ESR14 and the Bocconi research team, developed a conceptual framework for the analysis of EC BMs and identified four archetypes that represent the different ways in which ECs can organize their activities. These archetypes clarify the services and benefits that ECs can deliver both to their members and to society at large, thereby informing the design of market solutions, such as flexibility services to the electricity grid.

In parallel, ESR14 worked on the integration of electric vehicle charging stations (EVCS) into ECs, in collaboration with ESR15 and the Bocconi research team. The work consisted of developing a techno-economic-environmental optimization methodology, which was first applied to a university as a test case. The objective was to reduce both the cost of energy and greenhouse gas emissions (GHG), thereby addressing energy demand from buildings and transport in a holistic way. This research represents an initial step toward the comprehensive assessment of community-level energy consumption.

Overall, the joint efforts of ESR14 and ESR15 contribute to the goals of WP5 by providing a systematic framework for the analysis of ECs BMs, by clarifying their role within energy markets through the definition of archetypes, and by proposing innovative methods to integrate EV charging infrastructure into local energy systems. These results strengthen the knowledge base required to develop market solutions and BMs that support the feasibility and sustainability of distributed EES.

1.1 Objectives and structure of the deliverable

The purpose of this deliverable is to present the progress of WP5 activities, and the research outcomes achieved by the ESRs in the context of Deliverable D5.3, titled "Report including market solutions and business models to enable the growth and sustainability of distributed EES." This report focuses on two Individual Research Projects (IRPs), namely IRP14 and IRP15. IRP14 is related to energy value chains and markets development with the new paradigm of distributed EES, while IRP15 focuses on identifying enablers and barriers to foster the replicability and transfer of BMs for green energy systems. The results reflect the research achievements reached within the first 45 months of the project.

Specifically, the deliverable mainly focuses on market solutions and BMs that enable the growth and sustainability of distributed EES. The ESRs research is related to the topic of ECs, aiming to analyse the various BMs that exist and suggest solutions for the development of green energy systems. Initially, bibliometric analysis of ECs was performed, later BMs archetypes were analysed which found in the literature. After that, one BM archetype was taken into account and validated by performing feasibility studies. Finally, the deliverable presents the link between the research outcomes achieved and the overarching goals of WP5, contributing to the broader understanding of how innovative BMs can be adopted and replicated across different contexts within the green energy landscape.

2. General progress of the action

2.1. WP5 Objectives and tasks

The deliverable is part of WP5, "Green Economy Models and Management Systems," which addresses innovative energy management tools and BMs to meet the new challenges posed by the electric energy system. WP5 involves four IRPs, each focusing on distinct topics related to innovative management solutions and BMs. Specifically, IRP12 concentrates on developing sustainable strategies for Net Zero Energy buildings and user energy awareness using smart appliances; IRP13 explores digital twins of prosumers using socioeconomical factors and big data for optimization of customer's bill savings and the adoption of concepts of self-consumption and presumption; IRP14 focuses on energy value chains and markets developed with the new paradigm of distributed EES; and IRP15 is dedicated on identifying enablers and barriers to foster the replicability and transfer of BMs for Green Energy Systems. The research outputs aim to enhance understanding and promote the adoption of technological and business solutions that support the sustainable energy transition. WP5 included 5 Tasks:

- Task 5.1: Development of sustainable strategies for Net Zero Energy Buildings and Energy Awareness using Smart Appliances (UB, UNL).
- Task 5.2: Generation of digital twins of prosumers using socioeconomical factors and big data for Optimization of Customer's bill savings, (UB-SIEM-UNL).
- Task 5.3: Energy value chains and markets developed with the new paradigm of distributed EES (UB-UNL-CNR).
- Task 5.4: Identifying enablers and barriers to foster the replicability and transfer of business models for Green Energy Systems (UB, UNL, ECPE).
- Task 5.5: Elaboration of partial and final scientific reports (UB).

Tasks 5.1 and 5.2 have been completed and the corresponding deliverables submitted. Tasks 5.3 and 5.4 are ongoing and are scheduled to be finalized by September 2025, remaining on track with the project timeline. This deliverable specifically presents the final insights from Task 5.3, while the main results from Task 5.4 are addressed separately in Deliverable 5.4. Both ESR14 and ESR15 have successfully completed their research activities, fully meeting the objectives outlined in their respective IRPs (see section 2.2).

The work carried out in Task 5.3 provides a structured and validated analysis of the energy value chain and market developed with the new paradigm of distributed EES, focusing on EC initiatives. Through mixed-method approaches, including bibliometric literature review, semi-structured literature review, and techno-economic feasibility studies, this research has contributed significant new evidence to inform the design of scalable and context-sensitive BMs. These results directly support WP5's ambitions to inform business strategies, enable effective policy design, and promote sustainable energy innovation across diverse socio-technical contexts.

2.2. WP5 – IRPs and ESRs progress

The research activities carried out within IRP14 and IRP15 directly contribute to the objectives of WP5 and to the preparation of this deliverable.

ESR14 (within IRP14) focused on the techno-economic-environmental analysis of EVCS. The first stage of this research was conducted during the initial secondment at Nova University Lisbon (June–July 2023), under the supervision of Professor João F. Martin. In this phase, a methodology was developed to reduce both the Cost of Energy (COE) and greenhouse gas emissions for end-users. The analysis relied on optimization techniques applied to a university campus as a test case. The research was further expanded during the second secondment at the University of Extremadura (November 2024–February 2025), under the supervision of Professor Enrique Romero-Cadaval. In this phase, ESR14 applied advanced mathematical optimization methods, including genetic algorithms implemented in HOMER software, to assess EVCS integration at both university and community (building-scale) levels. The approach also considered the role of Virtual Power Plants (VPPs) in optimizing energy use[1]. During this secondment, ESR14 collaborated with ESR03, developing an integrated feasibility study for EVs and community buildings, with a particular focus on services for EC users.

ESR15 (within IPR15) carried out a bibliometric literature review aimed at mapping the academic landscape on ECs and identifying research gaps relevant to WP5 objectives. This work was conducted during the first secondment at

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[1] This work published as conference paper can be referred as "Ahmed, SM Masum, et al. "Techno-Economic Optimization of Electric Vehicle Charging Station with Virtual Power Plant–a University Campus Use Case." IEEE EUROCON 2025-21st International Conference on Smart Technologies. IEEE, 2025." DOI: https://doi.org/10.1109/EUROCON64445.2025.11073409.

the University of Extremadura (October–December 2023), under the supervision of Professor Patricia Milanes Montero[2]. During this period, ESR15 received training in bibliometric methods, particularly the use of VOSviewer software, and performed direct citation and keyword co-occurrence analyses. The results provided an overview of existing research, highlighted gaps, and informed the subsequent development of a targeted analytical framework to assess EC BMs. The research related to EC BMs have been carried out at Bocconi University in collaboration with the university's research team and under the supervision of Professor Edoardo Croci. The current research spans eight months, beginning in September 2024. The resulting paper was presented at a conference on May 22, 2025, and subsequently published [1] in IEEE Xplore in June 2025[3]. Specifically, ESR15 conducted a literature review and content analysis on the topics of EC BMs and developed an analytical framework consisting of five dimensions. This framework was then applied to define four distinct ECBM archetypes: the self-consumption model, the third-party model, the aggregator model, and the integrated services and e-mobility model. A detailed analysis of the methodology and scientific outcomes will be presented in the following section.

Table 1

General evaluation and current statues of ESR14 and ESR15.

ESR#	Starting date	General evaluation	Status
ESR14	01/09/2022	ESR14 is progressing well with the declared research objectives, and the research topic aligns with IRP14. Since ESR14's recruitment on September 1st, 2022, he has been actively involved in the project, fulfilling his duties by participating in two secondments in Portugal and Spain, respectively. During these secondments, ESR14 collaborated with researchers from Portugal and Spain, including ESR03, with whom he presented one conference paper. His conference paper has been presented in a flagship conference in Europe: IEEE EUROCON-2025. Another conference paper already published at Springer Nature at DOCEIS-2023. Additionally, he has submitted two journal articles, and one ongoing book chapter and has planned two more journal articles (in collaboration with ESR15). In terms of awards, ESR14 received the best conference paper award at DOCEIS-2023. ESR14 specifically addresses the topic of Renewable Energy Source (RES)-powered EVCS for ECs, which closely aligns with the objectives of WP5, particularly IRP 14. Two related research papers (one article and one conference paper) are reported as validation of effective market solutions for ECs members here: • The first article aims to conduct a feasibility study of RES-powered EVCS at the NOVA University Lisbon by performing an energy-economic-environmental optimization. This work has already been done and going to submit it soon to a reputed journal. • A study was conducted by performing a techno-economic feasibility analysis of RES-powered EVCS at NOVA University Lisbon with an aim to reduce the COE and GHG emissions, either through on-site RES integration or via a Virtual Power Plant (VPP). This work, already accepted and presented at IEEE EUROCON – 21st International Conference on Smart Technologies, and already published soon at IEEE Xplore (Scopus Indexed). The ESR will continue his PhD thesis in the upcoming months. Also, he will continue working on ongoing publications with IRP 14. Overall, the ESR has successfully achieved the goals of IRP 14 regarding the intended outcomes; therefore, the activities related to the deliverables' objective can be considered more than satisfactory	Finalising
ESR15	01/01/2023	The objective of ESR15 is aligned with IRP 15, focusing on identifying the enablers and barriers that promote the replicability of business models for green energy systems. ESR15 was recruited on January 1st, 2023.	In progress

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[2] The bibliometric literature review is planning to be published as journal article.

[3] Pantazis, Konstantinos, et al. "Energy Community Business Models Archetypes." 2025 IEEE 19th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG). IEEE, 2025. DOI: https://doi.org/10.1109/CPE-POWERENG63314.2025.11027308.

		So far, three publications have been produced: one journal article and two conference papers. Furthermore, on journal article has been completed and is under submission process. Finally, two more articles are in progress and are planned to be submitted in the coming period. Finally, ESR15 has collaborated with ESR14 on two more papers. ESR15 specifically addresses the topic of ECs, which closely aligns with the objectives of WP5, particularly IRP 15. Two related research papers are reported here: • A bibliometric literature review aimed at analysing the entire academic literature regarding ECs. This research serves as a preliminary step that supports the next phase of the study. This work has been completed but has not yet been published, since it was rejected and now is under resubmission as a journal article (see Sect. 3 deliverable description). • An analysis of various EC BMs. A tailor-made analytical framework was developed to facilitate the analysis of different EC BMs. Additionally, four distinct EC BM archetypes were defined. This work has already been presented at the CPE-POWERENG conference and has been published in IEEE Xplore (see Sect. 3 deliverable description). Overall, the ESR has successfully met the objectives of IRP 15 regarding the intended outcomes; therefore, the activities related to the deliverable's objective can be considered good. ESR15 is enrolled as a Ph.D. student at the University of Extremadura, with the goal of completing the program no later than June 2026.	ESR15 will be involved in the SmartGYsum project for a duration of 36 months, concluding on December 30, 2025.

3. Energy Community concept and Business Model analysis

3.1. A bibliometric literature review on energy communities

The new wave of 5D, decarbonization, decentralization, democratization, distribution, and digitalization mark a significant shift in the energy market [2]. This transition from a centralised monopoly to a decentralised model where different participants, including citizens, local authorities and private companies, can participate in the energy market [3]. Within this context, ECs have attracted a lot of attention, both in academia and in policy. Recognized as legal entities through two EU directives, the Renewable Energy Directive (RED) and the Internal Electricity Market Directive (IEMD), ECs aim to empower citizens, small and medium enterprises (SMEs), and local authorities to produce, consume, and manage their own energy [3].

Although citizen participation in the energy systems has a long history that goes back to the late 19th and early 20th centuries [4], ECs start to get recognition and develop in numbers, especially after the abovementioned directives were published that define the two types of ECs, namely RED and CEC. Currently, there are over 10,000 ECs that have initiated around 22,000 projects, and this number is expected to rise in the coming years [5].

However, the topic of ECs remains complex due to the various terms and definitions found in academic literature [6], [7]. Apart from the term "energy community," several similar terms exist in the literature, such as "community energy," "citizen energy community," "local energy community," and "energy cooperative" [7]. Furthermore, research from different disciplinary backgrounds has sought to analyse the composition of ECs, the benefits they offer to society, and the barriers they encounter in further development [8]. Some scholars aim to clarify the fluid meaning of "community" and propose definitions [9], [10], while others develop typologies of ECs based on energy citizenship [11]. Furthermore, other studies have examined the potential of ECs to democratize the energy system and promote justice [12], [13], [14].

The information presented indicates a notable increase in the number of studies focused on ECs in recent years. As a result, many scholars have undertaken literature reviews to map the existing body of knowledge related to the topic of ECs. For instance, Gruber et al. [7] conducted a literature review that highlights the current state of EC development. They specifically examined the various terminologies associated with ECs and identified the renewable energy technologies most frequently analysed in literature, such as wind and solar power, along with the main characteristics and structures of ECs. Similarly, Koltunov et al. [15] performed a comprehensive literature review and desk research to provide a detailed overview of the academic literature regarding the study and classification of ECs. The studies mentioned above have enhanced understanding of how the topic of EC has been addressed in academic literature. However, most of them either focus on a specific country or analyse the literature from a particular disciplinary perspective. For example, Koltunov & de Vidovich [16] conducted a literature review on ECs, concentrating solely on the social sciences. Thus, there is a noticeable gap in academic studies that encompasses the full range of current epistemic data related to the topic of ECs and that offers a comprehensive overview of the academic landscape. Hence, ESR15 conducted a bibliometric literature review regarding ECs, aiming to map all academic literature and identify the various research areas that have addressed this topic. The findings from this research represent an initial step that supports the subsequent phase of ESR15 research by helping to identify research gaps and develop research questions.

ESR15 conducted a bibliometric analysis by extracting papers from the Web of Science database and analysing them using the VOSviewer program. ESR15 utilized various keywords related to the topic of ECs, such as “renewable community of citizens,” “energy community,” “renewable energy community,” “local energy community,” “smart energy community,” and “zero energy community”. Only research papers that underwent a double or peer-review process were considered, resulting in the extraction of 1,445 research papers. Bibliometric analysis primarily serves two purposes: (i) performance analysis, which is descriptive and provides insights into the publication performance of authors' institutions or countries, and (ii) science mapping, which examines the relationships between research elements to reveal the dynamics and structures of a scientific field [17].

ESR15 engages in both descriptive analysis and science mapping analysis by employing various research methodologies. Specifically,

- Descriptive analysis: ESR15 performed a descriptive analysis to explore the evolution of research in EC. This segment of the study emphasizes the annual publication count and identifies the most influential authors, countries, and journals related to the topic.
- Science Mapping: Additionally, ESR15 conducted a keyword co-occurrence analysis to investigate the conceptual structure and highlight the main scientific themes associated with ECs.

3.2. Descriptive analysis

The research outcomes from this study indicate an increase in publications related to the topic of EC after 2017. Specifically, until 2012, the number of publications on ECs was limited to around six papers per year. However, from 2012 onward, a steady increase in publications was noted, with only 43 publications on the topic in 2017. Since then, there has been exponential growth in academic papers, reaching over 300 publications on the topic by 2022.

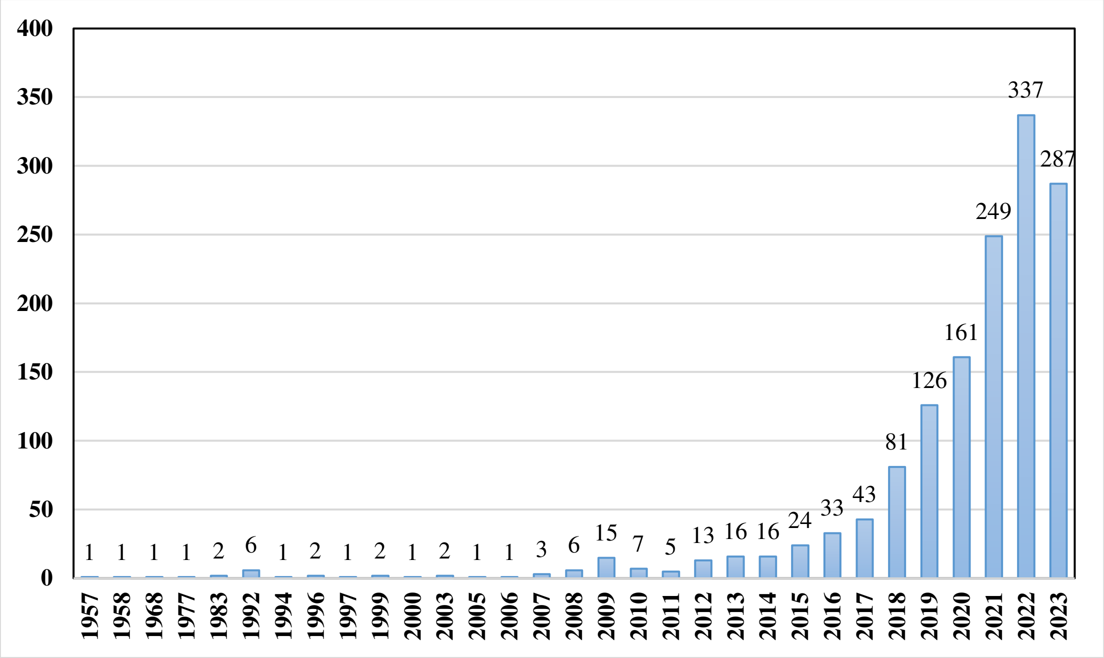

Figure 1: Annual publication related to the topic of Energy Communities.

The analysis reveals an uneven spatial distribution in publications on the topic, indicating that European countries are more productive in both the quantity of documents published and the citations received. Specifically, five out of the six most productive countries for publications are European: Italy, Germany, the Netherlands, Portugal, and Spain. In contrast, only one non-European country, the USA, appears in this group. When considering the number of citations, the results show a similar trend, with European countries still leading. The USA ranks first with 3,004 citations, followed by Italy and Germany, each receiving over 2,000 citations. The Netherlands and England are close behind, each with fewer than 2,000 citations. China rounds out the top six, having garnered approximately 1,300 citations.

Table 2

Most productive countries, in terms of number of papers published and citations

Country	Documents	Country	Citations
Italy	319	USA	3004
Germany	144	Italy	2887
USA	129	Germany	2562
Netherlands	115	Netherlands	1957
Portugal	111	England	1763
Spain	107	China	1306

The most influential journals in terms of the number of publications include *Energies*, which has 178 papers, followed by *Applied Energy* with 68 papers and *Sustainability* with 58 papers published on the topic of EC. However, when considering total citations, *Energy Policy* leads with 1,561 citations, followed by *Applied Energy* with 1,276 citations, and *Sustainability* Journal with 567 citations (see fig. 2). The most influential authors, each with over 200 citations, are listed in Table 2.

Table 3

List of authors with more than 200 citations.

Authors	Citations
Bauwens, Thomas	516
Auer, Hans	330
Vale, Zita	264
Guo, Jiacheng	237
Wu, Di	237
Liu, Zhijian	229
Yang, Xinyan	229
Zhang, Shicong	229
Soares, Joao	212

3.3. Science Mapping: Keyword co-occurrence analysis.

The second part of the analysis conducted by ESR15, namely the keyword co-occurrence analysis, revealed the composition of current literature and the research areas that have been developed in relation to the topic of ECs. Specifically, three main research areas have emerged and are depicted in different colours in the following picture (see Fig. 2).

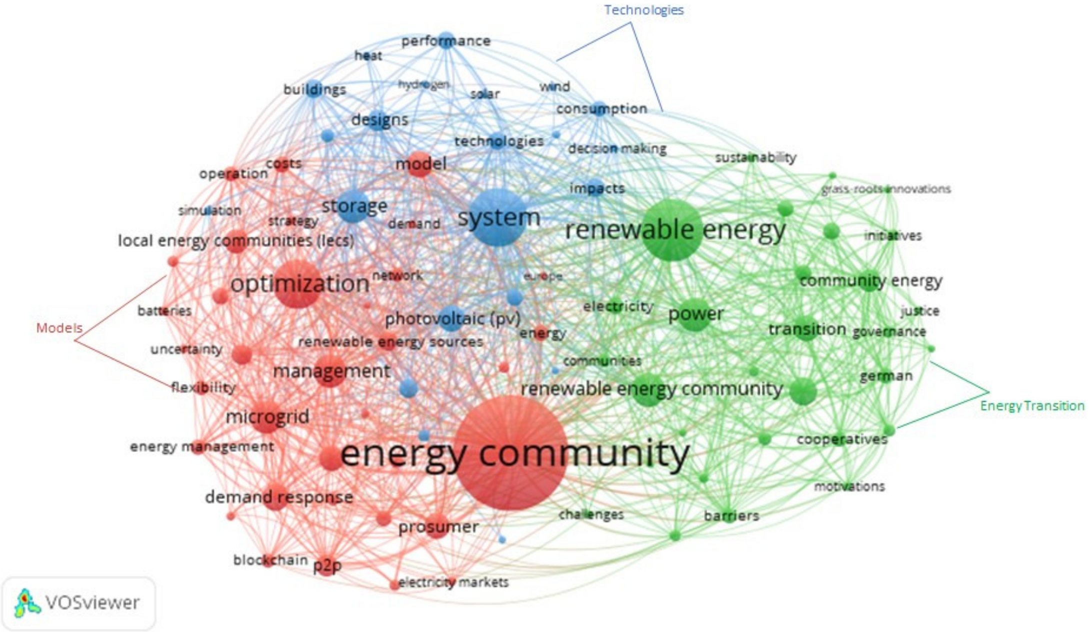

Figure 2: Keyword Co-occurrence analysis related to the topic of ECs.

The first cluster, represented in green, includes studies that analyze the topic of ECs by offering definitions and terminologies. The interpretation of the current research area is based on the types of keywords that appear most frequently within this specific cluster. Notably, the keywords that appear with high frequency include "renewable energy," "power," "renewable energy community," "energy transition," "transition," "community energy," "energy cooperative," "participation," "barriers," "grassroots innovations," etc. (see Fig. 2).

Based on the information provided, ESR15 designates the current research area as "energy transition." This designation stems from the focus of studies within this cluster on analyzing the role of ECs in the energy transition, alongside exploring relevant definitions, terminologies, barriers, and opportunities. For example, Walker and Devine-Wright [10] aim to clarify the fluid meaning of "community" by considering two crucial dimensions essential for understanding the full spectrum of "communities' social arrangements": the outcome dimension (i.e., "who the project is for" and "who benefits socially and economically") and the process dimension (i.e., who "participates," "manages," and has "influence" on communities). Moreover, Brummer [18] emphasizes that despite the various definitions of ECs in the literature, there is a general consensus among scholars that the concept includes two key elements: (i) the democratization of the energy system and (ii) the transition to more sustainable energy technologies. Additionally, some studies within this research area aim to investigate the role and potential of ECs in the energy transition by utilizing socio-technical transition theory frameworks such as the Multilevel Perspective (MLP) or strategic niche management (SNM) [19], [20].

The second research area highlighted in red examines various configurations related to ECs and their potential to transform the energy market by providing new services. Some of the most frequently occurring keywords in these research areas include "optimization," "microgrid," "management," "demand-response," "model," "prosumer," "peer-to-peer," and "smart grid." Consequently, ESR15 designates these research areas under the title "models," indicating that studies in this domain explore the different ways ECs operate within the energy market and their transformative potential.

For example, research by Koskela et al. [21] suggests that integrating electricity storage with photovoltaic (PV) power generation can improve economic efficiency compared to relying solely on PV power generation, thereby increasing residential energy production from PV systems. Additionally, electrical energy storage offers benefits such as enhanced self-consumption capacity, demand response capabilities, and the mitigation of high load peaks. Olivella-Rosell et al. [22] proposes a market-oriented framework for managing various flexibility services within the local energy market. This framework enables multiple stakeholders to buy and sell flexibility services. Specifically, an aggregator acts as the operator of the local market, facilitating transactions within the local EC. This approach could yield numerous advantages, including reduced energy costs and an increased distribution hosting capacity for the grids. In contrast, Sousa et al. [23] concentrate on peer-to-peer (P2P) markets, providing an overview that analyzes motivations, challenges, and various market designs.

Finally, the third research area depicted with the blue color focuses on the various technologies that EC has or can utilize. The most frequently appearing keywords in this research area are "system," "storage," "photovoltaic," "design," "self-consumption," etc. Therefore, ESR15 designates this research area with the title "technologies." The studies in this area focus on evaluating various technologies and services, including, among others, energy storage, electric vehicles, demand response, etc., from a techno-economic perspective. Additionally, optimization techniques and methods are proposed to enhance the performance of these technologies. For example, Terlouw et al. [24] developed an optimization model aimed at reducing the environmental and economic costs of ECs utilizing different battery technologies within a community energy storage (CES) system. They proposed two scenarios for CES: an energy arbitrage scenario and an energy arbitrage peak shaving scenario. Likewise, Liu et al. [25] developed a P2P energy optimization, management, and trading approach for hybrid renewable energy systems that include vehicle storage, batteries, and hydrogen vehicles. In their study, the authors compared different ECs featuring various types of vehicle storage, specifically hydrogen and batteries. Furthermore, they assessed different commercial applications and evaluated their performance from both techno-economic and environmental perspectives.

The importance of the current work goes beyond the identification of the research areas that have examined the topic of ECs. As previously mentioned, the size of the nodes in the figure (see Fig. 2) represents the number of occurrences of specific keywords in literature. Consequently, smaller nodes indicate that the associated topics have received less attention in academic literature, indicating potential research gaps. The first research area, "transition," reveals that the keywords "barriers" and "challenges" are significantly less prominent, as indicated by the smaller nodes representing these keywords compared to others that dominate this field of study concerning ECs. In the second research area, "models," there is a noticeable lack of keywords related to the ownership or BMs of ECs. Lastly, in the third research area, which focuses on the technologies associated with ECs, the absence of keywords such as "e-vehicle" and "charging stations" suggests that research on the relationship between ECs and e-vehicle charging stations has been relatively underexplored in academic literature.

The results of the current study highlight research areas that remain relatively unexplored and provide support for the subsequent research phases of ESR15 and ESR14. Specifically, ESR15 focuses on analyzing BMs and ECs, while ESR14 examines ECs that have implemented projects related to EVCS. The analysis and findings from this research are presented in the following sections of the current deliverable. Finally, the research gap concerning the barriers faced by ECs is addressed in the deliverable, "D.5.4, identifies enablers and barriers to promote the replicability and transfer of business models for Green Energy Systems."

3.4. Energy community business models

As already mentioned, ECs can engage in different activities and involve different types of actors, such as citizens, local authorities, or private actors, with various motivations and different goals [3]. Consequently, ECs can adopt different BMs depending, among other things, on their goals and technological choices. The BM describes the fundamental logic of a firm and how it operates to achieve its objectives. According to Ostervalder et al. [26], a BM outlines how an organization creates, delivers, and captures value. Nonetheless, as sustainability issues gain increasing attention, new definitions and perspectives have emerged in BM research, notably the concept of "shared value." According to Porter et al. [27] shared value can be defined as a way that a business "creates economic value in a way that also creates value for society by addressing its needs and challenges" [27]. This concept is particularly relevant to ECs, which prioritize sustainability objectives such as alleviating energy poverty, raising awareness of environmental concerns, and promoting clean energy solutions.

Based on the various interpretations of BMs and the complexity of EC configurations, many scholars have employed different methodological frameworks to study the topic of ECs [28], [29], [30]. ESR15, by conducting a literature review on ECs and BMs, identified that various frameworks have been utilized to analyze and categorize EC BMs, such as the business model canvas (BMC) [29], [31] and lean canvas framework (LCF) [32]. Additionally, some studies have sought to analyze and categorize EC BMs based on unique characteristics of ECs, such as membership and governance [33]. Currently, there is no widely accepted analytical framework in academic literature for analyzing and categorizing various EC BMs. To address this gap, ESR15 aims to identify and categorize all key dimensions present in the literature and highlight the most recurrent ones. Through this study, ESR15 aims to develop a customized analytical framework for EC BM analysis. This framework has been implemented, resulting in the definition of four distinct EC BM archetypes. These archetypes function as general theoretical models that illustrate mechanisms for describing the differences among EC initiatives in their processes of generating, delivering, and capturing value.

3.5. A tailor-made analytical framework

ESR15 conducted a semi-structured literature review to analyze the current literature on EC and BMs. To achieve this, papers were extracted from the Web of Science and Scopus databases. Various keywords were utilized based on the most frequent and relevant terms related to the topic of ECs [7], including "energy community," "community energy," and "renewable energy community." Additionally, to examine the unique characteristics of ECs, keywords such as "business models," "archetypes," "model," "cluster," "taxonomies," and "categories" were also incorporated. As a result of this search, 30 relevant papers were selected, comprising 25 journal articles, 4 reports, and 1 book chapter.

All papers identified through the literature review were analyzed to determine the most essential dimensions used for EC BM analysis. A content analysis was conducted for this purpose. Initially, 30 dimensions were identified; however, due to the thematic relationships among them, terms with similar meanings were consolidated, leading to the identification of 13 unique dimensions.

From those 13 dimensions, however, only 5 were kept because of the high occurrence in the literature and the relevance to the topic under investigation. ESR15 excluded dimensions that appear only sporadically or do not align with the primary objectives of BM analysis. Specifically, the dimensions that consist of the analytical framework found by ESR15 are "value proposition," "value capture," "main functions," "governance," and "membership." (see Tab. 1).

Table 4
The five dimensions of the tailored BM framework for ECs.

Dimensions	Description	Occurrences in the literature
Value proposition	Refers to EC's main objective and the benefits provided to its members and society.	21
Value capture	Refers to revenue stream and cost structure of the EC.	9
Main functions	Refers to the main activities, technologies and services of the EC.	12
Governance	Refers to the management, decision-making and control of the EC.	9
Membership	Refers to the different types and roles of actors participating in the EC as members.	16

The dimension that appears more in the literature is the "value proposition," which is the cornerstone for BM analysis. It appears 21 times, albeit in various terms, in the literature review, such as organizational purpose [3], goals [34], or benefits [35], and it describes the EC's main objective. Based on Osterwalder et al. [26], ESR15 defined the value proposition as the advantages members gain from EC services. "Value capture" is the second dimension of the analytical framework, noted 9 times in the literature review. It pertains to cost structures and revenue streams, although various terms are utilized in the literature, such as financial models [30], value-sharing mechanisms [36], and energy value capture [33]. These terms illustrate how ECs allocate profits among their members [37]. Therefore, all these terms were categorized by the ESR15 dimension, as they all relate to the methods by which the EC can secure value for its members or clients.

The dimension "main function" pertains to the key activities, technologies, and services employed by ECs, appearing 12 times in the review, albeit under varying terminology. Regardless of the specific terms used, they all highlight the crucial role of ECs in participating in diverse energy services and activities [37], which include, among others, energy self-production and consumption, energy sharing, energy supply, and retail. Furthermore, ESR15 incorporates terminology from studies that examine the technologies used by ECs [15], [38], [39], as these technologies are vital for achieving the objectives of ECs [33]. It is also important to note that the main function dimension includes both value creation and value delivery, outlining the functions that ECs must fulfil to generate and provide value to their members or the local community.

The last two dimensions that complete the BM analytical framework are "governance" and "membership." Governance refers to the management and control of an organization, as well as the interactions among its participants [40], and appears 9 times in our literature review. However, not all studies use the same terminology. For instance, Caramizaru & Uihlein [3] categorize ECs based on the extent of their "autonomy" and "effective control" of strategic assets, such as energy generation assets. "Autonomy" refers to the ability of ECs to remain independent from individual members or market actors participating in the community. "Effective control" implies that community members have the capacity to exert decisive influence over the EC's decision-making and operations [3]. Moreover, ESR15 includes in the governance dimension reports and papers that consider the legal forms of ECs, as these are closely linked to the governance structure. Cooperatives that operate as ECs typically follow the principle of "one member, one vote," while partnerships and other legal forms adhere to different principles, such as quotas or shares, utilizing various governance types.

The "membership" dimension is mentioned 16 times and pertains to the various types of actors involved in the EC, including citizens, SMEs, and local authorities, as well as their respective roles within the community. Scholars employ different terms, such as participants [3], members of the EC [33], or actors [39]. Reference [11] distinguishes between the types of actors engaged in ECs and examines their functions across different EC BMs. Some studies concentrate on the diverse types of actors who can join and collaborate with an EC [41], while others highlight their positions in the energy market, differentiating between categories like "prosumers," "pure consumers," and "storage operators" [2]. Consequently, the "membership" dimension in our analysis encompasses not only the types of actors but also their roles within the EC.

The five dimensions mentioned above form the analytical framework intended to serve as a conceptual tool for academics, policymakers, or even ECs to analyse and categorize various EC BMs. ESR15 utilizes this framework to define EC BM archetypes, which are detailed in the following section.

3.6. Energy Community Business Model Archetypes

As mentioned earlier in this report, an archetype is an abstract theoretical model that represents a set of mechanisms distinguishing EC initiatives based on how they generate, deliver, and capture value. Utilizing the 5-dimension framework, ESR15 identifies four distinct EC business model archetypes: the self-consumption model, the third-party model, the aggregator model, and the e-service and e-mobility model. These four archetypes are differentiated across all five dimensions of the analytical framework. A detailed representation of the archetypes is provided below.

3.7. Self-consumption model

The self-consumption model seeks to lower energy bills by establishing collective power plants that generate and utilize energy for members of the EC. In this way, it functions as a collective prosumer, opting to self-consume energy rather than selling it to the grid. This model protects EC members from price fluctuations and can benefit vulnerable households by combating energy poverty.

The value capture mechanisms of this EC BM archetype rely on various strategies. Initially, opt-in or opt-out fees are implemented for members so the community can cover the costs, like power plant installation and maintenance. In addition, members buy shares in the EC, increasing the community's share capital. Finally, annual fees can cover labour and other expenses. Nevertheless, ECs under this archetype typically rely on voluntary work and do not incur high maintenance costs. The largest cost is power plant installation, which can be raised through public funding or crowdfunding campaigns.

The main function of this model is to create and supply energy through a PV energy production system owned by the community, which supplies energy to the grid. However, different types of technologies, such as wind, can be applied. A licensed supplier assesses the community's energy output and deducts it from the total energy consumed by the community. This process of offsetting the energy produced against the energy consumed ensures that community members either pay nothing for electricity or only incur charges if their consumption exceeds their production.

Regarding the membership and governance, it should be noted that this EC BM archetype is citizen-driven, with different types of members, such as SMEs or local authorities, participating. All members can be considered collective prosumers, with no distinct roles within the community. To enhance community performance, the EC operation may assign specific responsibilities to certain members. The governance structure is typically based on the cooperative model, applying the one-member-one-vote principle.

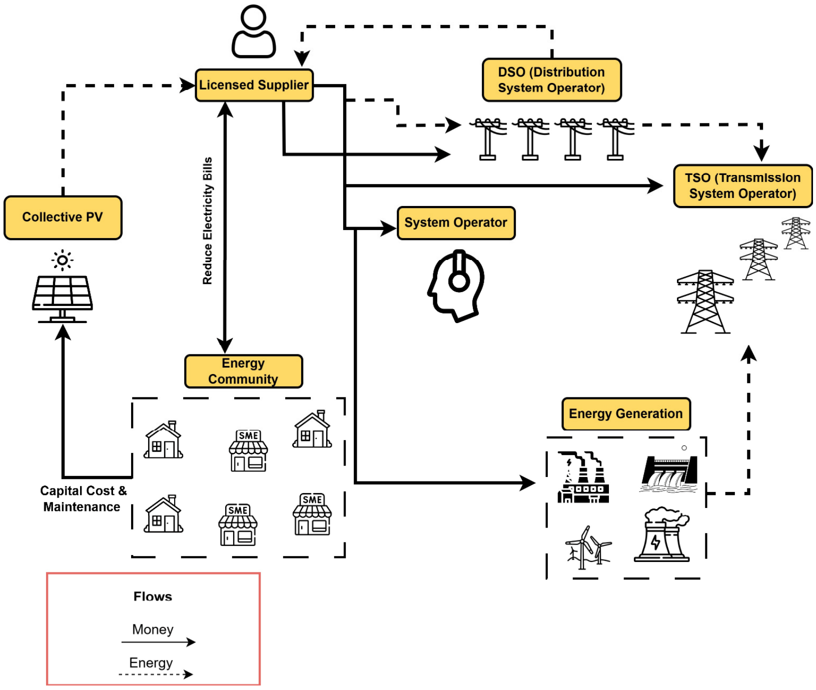

Figure 3: Self-consumption business model archetype.

3.8. Third-party model

The value proposition of third-party modes centers on lowering energy costs for EC members by enabling collective purchases of renewable energy at reduced prices or by facilitating the rental of energy production assets provided by third parties. In this EC business model archetype, the third party plays a vital role as an external stakeholder, assisting in the establishment and operation of the EC by offering energy services, providing technical and management support, or potentially financing the entire project.

There are two distinct mechanisms for value capture, one for the third party and another for the EC members. The value capture mechanism for the third party relies on a long-term revenue stream from the EC members, which can occur through the sale of energy or services at predetermined prices via long-term agreements or through the lending of energy production assets to the ECs. For the members of the ECs, the value capture is derived from reduced electricity bills and the fact that the third party assumes responsibility for the project. As a result, there is no financial risk or maintenance cost burden for the members of the EC.

The main function of this model is to facilitate energy purchases by establishing an EC that serves as an energy buyer. In this arrangement, a third party is responsible for the installation and maintenance of the energy production project. Consequently, this third party oversees and manages the project. Because EC members rely on the third party to deliver specialized services tailored to the community's needs, they are excluded from decision-making and control regarding energy production assets. Typically, this EC model encompasses residents or small and SMEs in proximity, such as those in large building complexes, social housing, or small towns. All EC members are consumers who own the properties where the power plants are located.

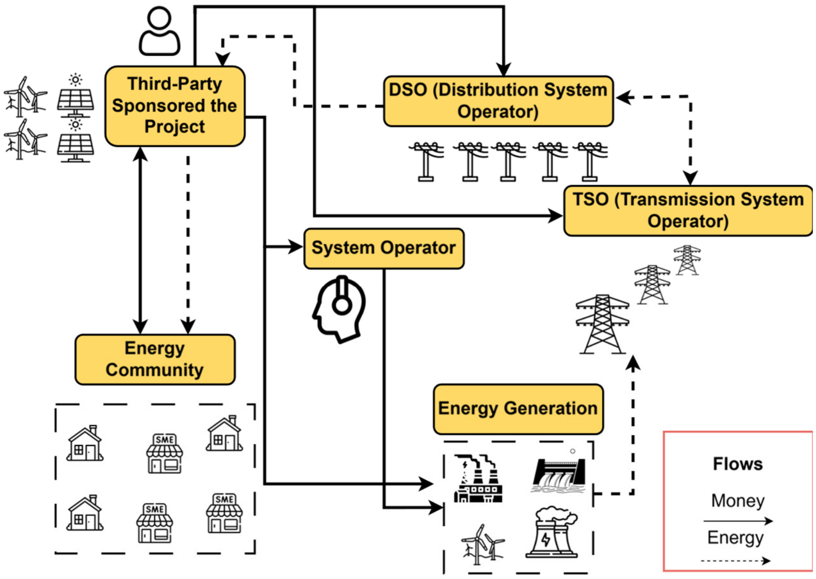

Figure 4: Third-party business model archetype.

3.9. Aggregator model

The value proposition of the EC aggregator archetype lies in the benefits that economies of scale provide for managing energy production and demand. An aggregator can dispatch energy more efficiently than a single agent or an EC with few members that act individually, optimizing the energy it produces and consumes while also offering flexibility and balancing services to the grid.

The value capture mechanism of this archetype varies by member, with some acting as prosumers, some as producers, and others as consumers. It is important to note that all EC members are responsible for owning, financing, and installing the storage systems and technologies necessary to monitor and optimize services. This arrangement allows the aggregator to save energy, while prosumers can earn revenue from the energy they supply to consumers or the grid. Additionally, revenue for the aggregator can be generated through opt-in and opt-out mechanisms, as well as through fees for services provided to external entities. However, the distribution of revenues depends on the roles of the members and the services they provide.

The main function of this archetype centres on the concentration of total supply and demand within a community. In this context, producers, or prosumers, members of the community, supply energy to other members of the community or to external stakeholders, such as grid operators. The aggregator plays a crucial role by providing energy, flexibility, and ancillary services on both the supply and demand sides. It can store excess energy from the system or transfer surplus energy generated by the community back to it. Additionally, the aggregator utilizes a platform for daily operations to coordinate the various members of the EC. While the implementation of this model may vary, its fundamental function involves using the platform to manage energy sharing and optimize demand management within the community, as well as to facilitate interactions among members and external entities.

The membership of this archetype may vary; however, it is evident that it can involve a range of actors, including citizens, local authorities, and private entities. It is important to note that EC members may assume different roles, as previously mentioned; some may act as prosumers, while others may be simple consumers. Despite these varying roles, all members share a common interest in energy sharing, participating in the energy market, and being managed by an aggregator. Regarding governance, all members take part in decision-making processes, and energy assets can be owned and controlled either individually or collectively. However, the aggregator oversees, manages, and facilitates interactions with suppliers and network operators.

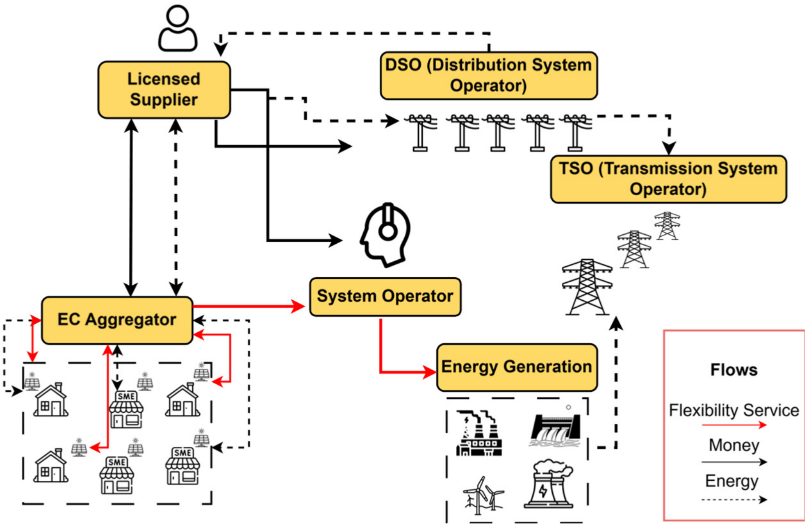

Figure 5: Aggregator business model archetype.

3.10. Integrated energy services and E-mobility model

The value proposition of this archetype lies in offering integrated, low-carbon services that can support various actors. Consequently, BMs that fall under this EC archetype are characterized by the diverse range of services they provide to both their members and external stakeholders. The value capture mechanisms differ among the participating actors, the services utilized, and their respective roles. Consequently, e-vehicle services, energy savings, and opt-in and opt-out membership fees can function as revenue streams.

The main function of this EC shares characteristics similar to that of the previously mentioned aggregator archetype, as the members of the EC have specific roles and provide services both within the community and externally. However, this model also encompasses activities that extend beyond energy generation and flexibility provision, offering additional services such as EVCS and car sharing.

The membership structure includes various types of participants, such as citizens, local authorities, and SMEs. Members of this EC business model archetype can hold the EC's assets collectively or individually and engage in decision-making based on their respective quotas. The EC in this model provides management services and collaborates with suppliers and network operators, offering tailored solutions to secure long-term contracts. Moreover, this model is designed to adapt its services to meet the specific needs of its members.

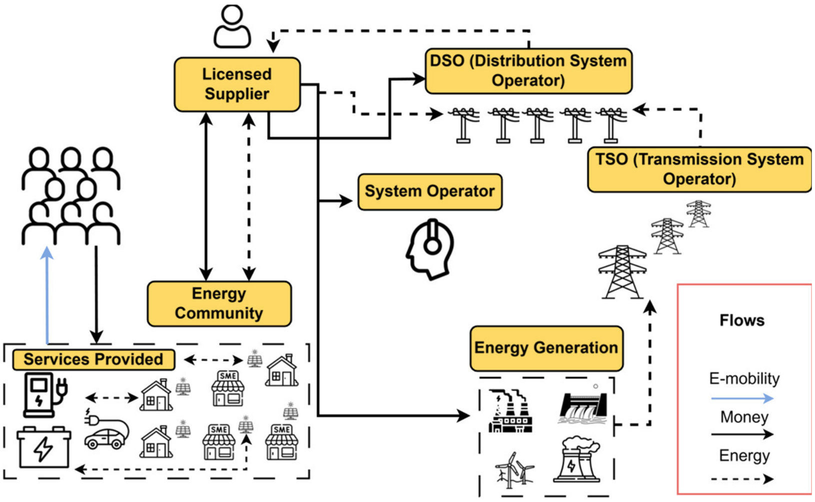

Figure 6: Integrated energy services and e-mobility business model archetype.

4. Electric Vehicle Charging Station for university (Case Study I: RES-powered EVCS for a university)

After analysing four BM archetypes, attention turned to assessing the viability and opportunities of introducing electric vehicle services, such as EVCS offered as a service for ECs members and other end-users. The purpose of this subsection is to evaluate how renewable energy source (RES)-powered EVCS can support both university authorities and energy users from a technical and economic perspective, positioning them as innovative energy services within ECs. The subsection presents the results of a techno-economic assessment of RES-powered EVCS, highlighting their potential to enhance the sustainability and economic viability of ECs. Demonstrating the integration of EVCS into ECs is crucial, as it shows how such solutions can enable local citizens to achieve greater energy independence while advancing the transition toward sustainable and decentralized energy systems.

4.1. Background and Literature Review for Case Study I

More than 25% of the EU's total CO_2 emissions were produced from the transportation sector in 2022, where road transport (cars and heavy-duty trucks) is responsible for 71.7% of total emissions produced by the transportation sector. 92% of cars in the European Union (EU) are Internal Combustion Engine (ICE) vehicles powered by fossil-fuels (petrol and diesel) according to the European Automobile Manufacturers' Association, or ACEA. To reduce emissions, the EU fleet-wide CO2 emission target set for both cars and vans is 0 g CO2/km from 2035 onwards, subsequent to achieving a 100% emission reduction [42]. The market must be able to accept new EV customers, since EVs are essential in mitigating GHG emissions. Furthermore, EV consumers are facing several barriers to buying EVs, including a lack of knowledge [43], high purchase cost [44], and limited autonomy, but mostly about the lack of EVCS availability [45]. The lack of availability of EV charging infrastructure slows down interest in buying EVs in many countries [46], [47]. Therefore, to increase EV adoption and fulfil the demand of EV users, adequate EVCS's are required to charge their EVs. Nevertheless, the majority of EVCS's rely on fossil fuels (as 60.65% of total energy generation of the world is from fossil fuels), resulting in higher grid emissions as most of the EVCS powered by energy grid.

EVCS can be integrated from the local level, including ECs, to enhance the integration and solve some technical and infrastructural barriers. ECs are primarily responsible for producing RES for self-consumption and energy sharing among EC members. However, one of the primary challenges faced by ECs is the intermittent nature of RES, such as solar and wind, which can lead to imbalances between energy production and consumption, and solar energy is not available during nighttime. The intermittent nature of renewable energy sources and the lack of energy availability during nighttime can significantly hinder the operation of ECs, where EVs can be utilized as a key storage solution. EVs function as decentralized storage units with batteries that store excess energy during peak production and release it during periods of increased demand. In addition to storage, EVs can provide vehicle-to-grid (V2G) and vehicle-to-home (V2H) services, enabling bidirectional energy flows that support both the grid and individual households. But adapting EVs and charging them with renewable EVCS is a key option, and it can be worked as a service for ECs to generate benefits for their members. These services support the grid and provide flexibility to EC members. In the next part a literature analysis was done to see what the progress in current research field regarding the EVCS are. A summarized literature matrix of the selected papers is presented in Table 5.

Table 5

Summarized literature matrix of the selected paper.

Ref	Location	Year	Simulation tool/Method	Application	Charger Method	MG configuration	Charger number	Economic Parameters
[48]	Portugal	2022	HOMER Grid	Not Found (NF)	Leverl-2 (L-2), Leverl-3 (L-3)	PV-ESS-Grid	2	COE, NPC, CAPEX, OPEX
[49]	Romania	2019	HOMER Pro	Residential	L-2	PV-Grid-WT-BESS	2	COE
[50]	Portugal	2021	GAMS, MILP	University	L-2	PV-Grid	110	COE
[51]	Bangladesh	2023	FLC, RNN, LSTM, HOMER Pro	Airport	L-3	PV-WT-Grid	25	COE, NPC, CAPEX, OPEX
[52]	Qatar	2022	HOMER Pro	NF	L-3	PV-WT-Biomass-ESS	50	COE, NPC
[53]	Turkey	2019	ETAP	NF	L-2	PV-Grid	100	Not Found (NF)
[54]	NF	2020	MILP, GAMS	NF	Leverl-1 (L-1), L-2, L-3	BESS-WT-Grid	14	CAPEX
[55]	Australia	2020	MATLAB 2018b	NF	NF	WT-PV-CSP-Grid	NF	COE, CAPEX
This work	Portugal	-	Python, HOMER[4]	University	L-3	PV-WT-Grid	25	COE, CAPEX, OPEX, NPC

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[4] HOMER is a simulation software that assists users to perform energy-economic optimization with RES's [63].

Costa et al. were working on an energy system for EVCS by proposing an energy system considering PV-Energy Storage System (ESS)-Grid by utilizing HOMER Grid software in Portugal [48]. The energy system was designed for two levels of EV chargers (L-2 is semi-fast charging, and L-3 is fast charging) [48]. To develop the energy system, 30,324 euros were required as Capital Expenditure (CAPEX) and achieved a COE of 0.156 euro/kWh.

Osorio et al. proposed a model for EVCS with solar rooftop in Portugal [50]. The model was developed in the General Algebraic Modeling System (GAMS) using the Mixed Integer Linear Program (MILP) solver. PV-Grid was considered an energy system for the EVCS, where 110 EVs were recharged from EVCS, whereas only an L-2 charger was taken into consideration. To conduct the analysis different energy prices were considered and profitability was achieved by proposing the EVCS. Hence, State of Charge (SOC)[5] and load profile estimation are not clearly mentioned in the research. Turan et al. investigated the effect of EVCS equipped with roof-mounted PV panels in Turkey [53].

Furthermore, Hasan et al. proposed an EVCS for an International airport in Bangladesh [51]. They utilized Fuzzy Logic Control (FLC), Recurrent Neural Network (RNN), and Long Short-Term Memory (LSTM) to develop the load profile, and they conducted an energy-economic assessment using HOMER Pro software. Also, the most optimal energy system was the PV-WT-Grid for 25 EVs. Also, to achieve the best results, 3.6 million $ was required as CAPEX for setting up the charging station, which had 84.3% of renewable energy fraction with a payback period of 6.30 years [51]. Although SOC estimations or assumptions are not clarified in the research. In addition, Wahedi et al. proposed a stand-alone RES-based EVCS for four cities in Qatar [52]. In this research work, the combination of the best configurations was Photovoltaic, Wind Turbin, Biomass and Energy Storage Systems (PV-WT-Biomass-ESS). They used HOMER Pro software to optimize the COE, and their proposed design could charge 50 EVs simultaneously. Moreover, the COE of their proposed system was between 0.285 to 0.329 $/kWh. Since this was a proposed EVCS, load profile design assumptions could be justified in the study, because without proper assumptions, the feasibility study will not be reliable.

After analysing current literature [48], [49], [50], [51], [52], [53], [54], [55], only some of these studies mentioned how they collected data or prepared the load profile with collected data or estimation. It is crucial to consider predicting or estimating load profiles to understand the electricity demand of EVCS. Therefore, it is crucial to estimate the load profile with better estimations.

Moreover, the majority of EVCS's are directly linked to the traditional electrical grid, which in several areas continues to depend significantly on fossil fuels like coal and natural gas. Consequently, charging EV's with grid energy still generates considerable GHG emissions, particularly if the electricity is not derived from RES's. This constrains the environmental advantage of EV adoption. Consequently, to efficiently reduce fossil fuel energy usage and enhance sustainability, it is essential to establish and deploy EVCS's powered by RES's, such as solar or wind energy. Therefore, the main goal of our study is to perform an energy-economic[6]-environmental optimization by conducting the feasibility of RES-powered EVCS at the NOVA University Lisbon, Caparica, Portugal (this location is considered as a pilot case[7]).

4.2. Methodology of the Case Study I

An energy resource assessment was conducted to determine the suitability of the EVCS site, considering solar radiation, wind speed, and grid connectivity options. Following this investigation, solar and wind energy were identified as the primary renewable energy sources. PV panels were selected based on favourable solar conditions, with an average daily radiation of 4.86 kWh/m²/day. Additionally, wind turbines (WT) were chosen due to the site's proximity to the sea, which offers favourable wind conditions, averaging 6.68 m/s [56]. A grid-connected architecture was selected, allowing for the import of energy during periods of insufficient renewable production and the export of excess electricity to the grid, thus generating potential revenue streams. Figures 7 and 8 show the monthly profiles of solar radiation (including clearness index) and wind speed, highlighting the renewable energy potential of the chosen area.

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[5] The term "SoC" refers to the ratio of a cell's operational capacity to its maximum achievable capacity [64].

[6] Techno-economic analysis (TEA) is a technique for assessing a technology's financial performance, according to the US Department of Energy (DOE). A TEA evaluates a technology's total worth, enabling analysts to appropriately balance costs and advantages [65].

[7] Many people arrive every week at the university, including teachers, researchers, staff, students, and visitors. As a lot of people came to the university by utilizing different transportation systems (including cars) we considered this location as a living lab for our analysis.

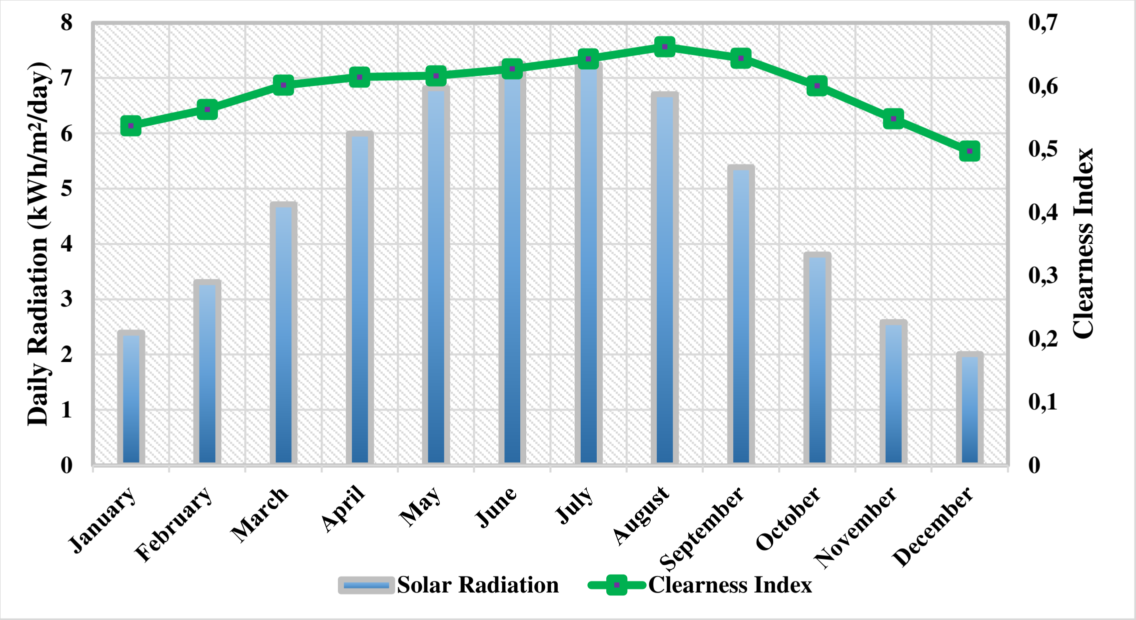

Figure 7: Monthly solar radiation to understand the potential of the selected location with clearness index.

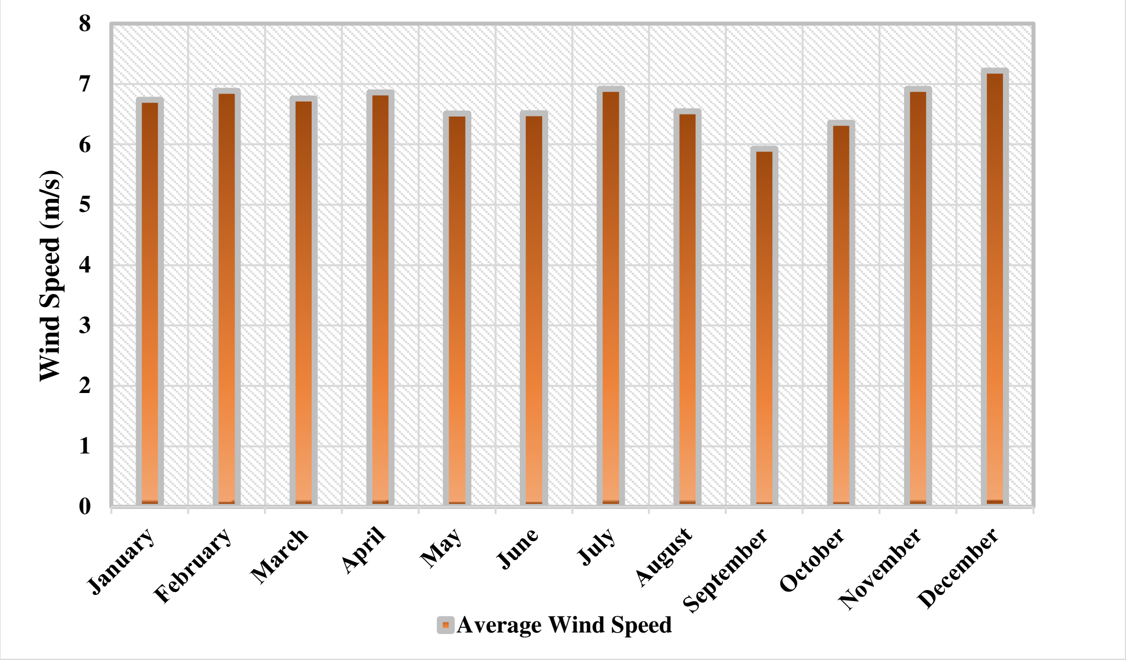

Figure 8: Wind speed to understand the potential of the selected location.

At first, data (TOA and TOD of parked cars in the university) is collected from the FCT NOVA parking lot, to understand the occupancy of the vehicles and their average staying time in the parking lot. When the dataset was analysed, certain challenges were identified: due to the General Data Protection Regulation (GDPR) law, it was not possible to accurately identify when a vehicle arrived or left the university. Therefore, specific information could not be found about which car would arrive at or leave the university. However, the data on the TOD and TOA of the cars are available. A Python script was written with a developed algorithm by utilizing the first in first out (FIFO[8]) method [57]. As we found in the literature, many researchers employed the FIFO method for EVCS parking lot scheduling [58], [59], [60], [61].

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[8] FIFO means "First In, First Out" and is an asset-management and valuation method in which assets produced or acquired first are sold, used, or disposed first [66].

To calculate the load of EVCS, equations are required; therefore, in this subsection, two equations are developed to estimate the load profile. With the first equation, the number of EVs are calculated that arrive every day in the parking lot by employing equation (1).

$$N_{T\_EV} = N_{T\_C\_E} * A_{P\_EV} \tag{1}$$

N_{T_EV} is the Number of EVs, $N_{T\_C\_E}$ is the number of cars arriving every day, A_{P_EV} is the assumed percentage of EVs. Also, the load estimation will be done by utilizing the data curation output precisely the output of the cars arriving in one day and multiplying with pattern percentage, the dedication hour to charge EVs and the SOC power level by utilizing equation (2).

$$L_{Est} = N_{T\_EV} * A_{PP} * t * P_{SOC} \tag{2}$$

Where Load Estimation denotes as L_{Est} , Total EV number is N_{T_EV} , Assumed Pattern Percentage indicates as A_{PP}, Hour is t, and Starting Power of Charger at different SOC levels denotes as P_{SOC}. After designing the load profile from equation (2), this load profile will be fed with collected energy-economic-environmental parameters into the HOMER optimization tool for the EVCS integrating a decentralized microgrid.

After developing the equation, the scenario development has been done. In energy-economic-environment feasibility studies, a few scenarios are considered when analysing the developed energy system. Overall, four scenarios were considered to conduct our analysis: (i) Scenario-1 (S1) is PV, WT and Grid, (ii) Scenario-2 (S2) is PV and Grid, (iii) Scenario-3 (S3) is WT and Grid, and (iv) Scenario-4 (S4) is only Grid (Base Scenario). In the S1, energy is supplied through the grid and on-site RES combined with PV, WT, reducing reliance on the conventional grid. S2 incorporates a PV and grid facility as backup energy. On the other hand, the main source of energy is WT and utilizes the grid as a backup system for buying energy from the grid. S3 is dedicated to WT instead of PV but similarly grid connections are available like S1 and S2. Furthermore, the S4 serves as the baseline, where EV's are charged solely from the grid without any direct integration of RES. This scenario provides a reference point for evaluating the performance of the other three scenarios.

The system sizing was done with the assistance of HOMER, a built-in optimizer. First, the auto optimizer option was utilized, and, later, the different component capacities were calibrated manually by setting the upper and lower limits of the system as constraints. Afterward, the software iterates several times to obtain the best possible solution for various configured systems. Techno-economic analysis was conducted through the input of estimated load, technical, economic, and environmental data from research papers and reports into HOMER software. Energy-economic optimization uses HOMER to compute Net Present Cost (NPC[9]), CAPEX[10], Operational Expenditure (OPEX[11]), COE[12], and CO2 reduction. Table 6 displays the summarized economic analysis of Case Study I.

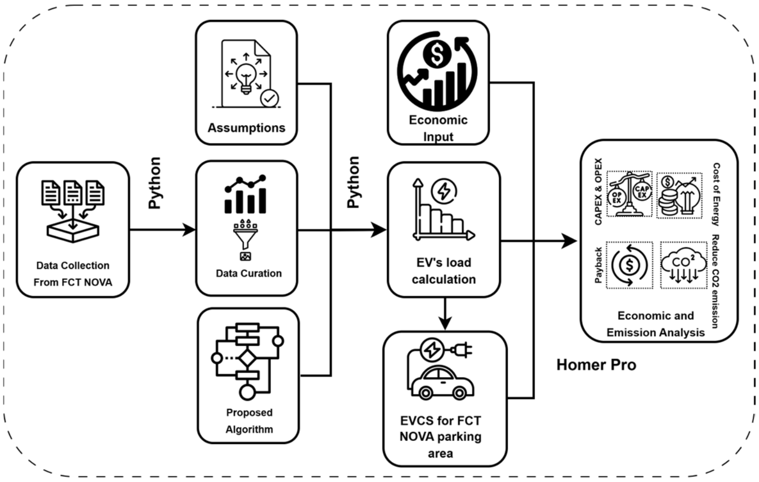

Figure 9: Methodology of the work.

4.3. Results of the Case Study I

Table 6

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[9] The NPC is the difference between the total cost of the project and the revenue generated by the system during the project period [67].

[10] CAPEX refers to an organization's funds to acquire, upgrade, or maintain physical assets such as property, buildings, technology, or equipment [68].

[11] OPEX or Lease Operating Expenses (LOE), lifting, or production costs, refer to items with a useful life of one year or less. Their costs are recorded as expenses in the accounts [69].

[12] The COE is defined as the annual cost ratio to the supplied electrical load [67].

Summarized Economic Analysis results of Case Study I

Scenario	NPC (million $)	CAPEX (million $)	OPEX (million $/year)	COE ($/kWh)
S1	13.62	0.74	0.35	0.23
S2	5.66	3.67	0.023	0.027
S3	11.16	3.34	0.21	0.11
S4	5.89	5.89	-0.045	0.019

Among the four cases, S1 has the highest NPC of 13.62 million $. With a COE of 0.23 $/kWh, S1 leads in terms of achieving lowest COE among four scenarios. Additionally, S1 has the lowest CAPEX at 0.74 million $, primarily due to its allocation to network-related expenses. Among the four cases, S1 has the maximum OPEX. Moreover, S2's NPC is 5.66 million $, higher than S1's NPC. Hence C2's OPEX is 0.023 million $/year. Furthermore, S2 has a CAPEX of 3.67 million $. Besides, S3 has an NPC of 11.16 million $. The OPEX of S3 is 0.21 million $/year. S3's CAPEX also comes at 3.34 million $.

Among the four cases, S4 has the least NPC of 5.67 million $. On the other hand, S4 had the best CAPEX at 5.89 million $. Nevertheless, with the highest CAPEX, S4 is regarded as the best scenario among the four cases. Furthermore, S4 has the lowest -0.045 $/year OPEX. Conversely, S4 has the lowest energy purchase and the largest energy sales from the grid. Therefore, in the most ideal case, economic parameters were calculated in the best-case comparison to the grid scenario; so, NPC and COE in the best cases are lower than in the grid cases as base.

This study's results demonstrate that the implementation of EVCS is both technically and economically viable within the analysed scenario. This substantiates the feasibility of extensive infrastructure development as an essential facilitator of the EU's shift to electric transportation. However, there are several limitations to this study. First, the percentage of EVs among cars arriving in the parking lot was estimated. This is an assumption made to estimate the load profile as are proposing this EVCS for the next 25 years. The second constraint of our work is that only considered the most sold EV car brand in Portugal. In our future work, different EV models and hybrid EVs will be considered to determine their feasibility with EVCS. Also, machine learning techniques will be integrated to predict load profiles for the EVCS. Furthermore, a sustainable service for the university's people will be planned. Categories of actors will be examined who can cooperate with for investments and offer a sustainable service. Furthermore, further studies must be performed globally to check their feasibility among various parts of different countries.

As observed, this case study is quite helpful for universities planning to build an EVCS and can be replicated to develop EC projects in the following case study combining university and community settings.

4.4. EVCS for EC (Case Study II: RES-powered EVCSs for a Building Community and a university)

In Case Study I, a university campus is considered to evaluate the technical and economic feasibility of a RES-powered EVCS. While this case study does not focus on an existing EC, a university campus is chosen because of its high energy consumption by many users and its local generation potential, which is similar to that of an EC. These similarities make university campuses ideal for testing EVCS. Furthermore, the optimisation analysis conducted for this Case Study I was conducted in a single step. In contrast, Case Study II involves integrating a building community with the university campus. The main difference lies in the optimization analysis methodology and comparison with and without VPP, which now employs a two-step optimization process and incorporates VPPs to improve the technological advancement of energy integration. VPP is considered for integrating new solutions into the energy grid. VPPs coordinate distributed resources (PV, energy storage, and EVs) to optimize energy flows, offer flexibility services, and increase economic and technical feasibility, unlike Case Study I, but it can operate remotely as well. VPPs enable decentralized RES production and EV within VPP frameworks.

Techno-economic analysis of RES-powered EVCS can deliver useful results such as (a) assist ECs' managers to understand the initial investment and possible profitability, (b) optimize energy-economic parameters and see their variances before even the project is built, and (c) convince investors to invest in sustainable projects with validation of the payback period.

4.5. Background and Literature Review for Case Study II

Many EVCS operate on carbon-intensive energy sources, limiting potential emissions reductions. To mitigate this issue, integrating RES with EVCS, either on-site or through VPP[13], is a promising approach to reducing GHG emissions and improving overall energy sustainability in the transport sector. However, the intermittent nature of RES, along with challenges related to energy storage and the spatial requirements for RES installations, complicates the implementation of EVCS powered by RES [4]. Therefore, the techno-economic feasibility of such solutions remains an area that needs to be examined.

Some studies attempted to analyse EVCSs from a techno-economic point of view, considering different techno-economic parameters. Arslan and Karasan examined the economic and emission impacts of VPP development in networks with plug-in hybrid EVs [5]. Moreover, Alabi et al. suggested a unique hybrid robust-stochastic approach to facilitate the optimum scheduling of a Zero-Carbon Multi-Energy System (ZCMES) using a VPP, taking into account EV adaptability while calculating OPEX and revenue [6]. Furthermore, Wang et al. developed a Deep Reinforcement Learning (DRL) approach for a VPP including EVCSs. The findings indicate that the VPP agent is capable of acquiring the strategy for selling energy to EVs, optimizing the scheduling of Distributed Energy Resources (DERs), and formulating a bidding strategy for engagement in the electricity market [7]. Besides, González-Romera et al. proposed an Energy Management System (EMS) for a residential VPP by incorporating PVs, Battery Energy Storage System (BESS), and EVs. They employed a Genetic Algorithm (GA)[2] to optimize energy costs and improve technical aspects by changing their scheduling [8]. Moreover, Alabi et al. proposed a deep learning approach (GRU-BiLSTM) and optimization model for multi-energy systems by the inclusion of EV's and carbon capture systems [9].

Although the above-mentioned studies have boosted research in this area, they still present some limitations, as a comprehensive assessment of economic viability has not yet been fully addressed. For example, Wang et al. considered profit, EVCS cost, and penalty cost. However, they did not calculate the overall economic feasibility [7]. Similarly, Alabi et al. did not consider key economic aspects such as COE and CAPEX [9], while González-Romera et al. did not perform a detailed economic analysis [8]. Therefore, a gap exists in academic literature due to the lack of robust techno-economic analysis that encompass both key economic parameters and technical comparisons between on-site RES production and storage and VPP. Hence, to address this gap, the goal of this work is to perform a techno-economic feasibility analysis of combining an EVCS with a VPP or on-site RES at the NOVA University Lisbon and considered residential-load3. This study seeks to provide insight into both the economic and environmental benefits of using RES or VPP-supported EVCS infrastructure. H. The main contribution of this study is performed one-layer technical optimization and two-layer economic optimization for energy systems serving an EVCS and residential load.

4.6. Schematic diagram of the prototype

To conduct this work, first, data were collected from a specific location to perform the analysis, which is NOVA University Lisbon. Later, for the residential load, a building dataset was utilized [13]. By combining these two datasets a load profile14 was developed. This load profile, technical and economic data was entered into the HOMER [14]) software to perform a first layer technical and economic optimization. After performing the first layer optimization, the CAPEX, OPEX, COE, NPC, and CO_2 emissions rate were obtained. Then, the techno-economic output of HOMER was given as input to MATLAB. In MATLAB, GA was used to perform the second layer of economic optimization. In Fig. 10, displays the two-layer optimization methodology for EVCS.

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[13] A Virtual Power Plant (VPP) is described identically to an autonomous microgrid [25]. VPP can work as a distant energy storage and energy generation plant. Also, VPP is an aggregation of decentralized units whose operations for the power grid are managed by a unified control system [26]. These units could encompass electricity producing systems such as biogas, wind, and photovoltaic energy conversion systems, cogeneration hydroelectric power plants, electricity consumers, and electricity storage facilities [26]. A VPP can play a vital role in energy export and import to the grid [27]. Also, it can work as an aggregator [28]. The energy generator and grid operator formalize an agreement that may include net metering or virtual accounting, ensuring hourly alignment between energy supplied to the grid and withdrawn by the EVCS. These agreements may also consider EVs as storage or assume full generation capacity of the RES facility.

[14] A load profile is a graph depicting power consumption over time, whereas load profile diagram illustrates accumulated power consumption in relation to operating period [30].

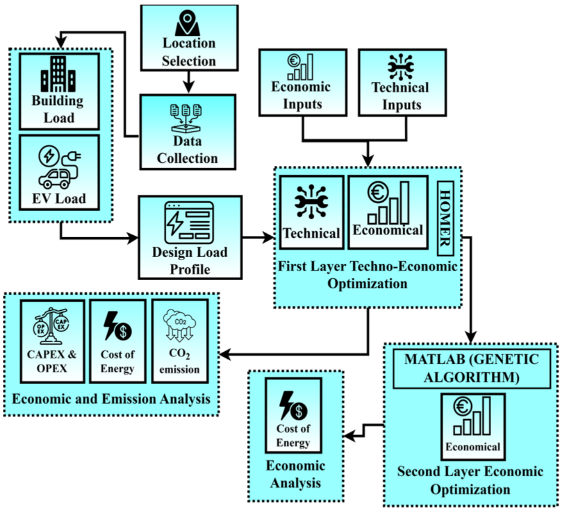

Figure 10: Methodology of two-layer optimizations for EVCS [62].

In techno-economic feasibility studies, a few scenarios are considered to analyse and check which one is better for the developed energy system. Overall, three scenarios were considered to conduct our analysis: (1) First Scenario-FS (Base scenario-BS) is a G2V infrastructure, (2) Second Scenario-SS is EVCS with RES on-site including BESS technologies, and (3) Third Scenario-TS is EVCS powered by VPP. Fig. 2 displays three considered cases in this work. The FS serves as the baseline, where EV's are charged solely from the grid without any direct integration of on-site RES generation. This scenario provides a reference point for evaluating the performance of the other two scenarios. In the SS, energy is supplied through on-site RES generation combined with a BESS, reducing reliance on the conventional grid. TS incorporates a VPP for remote energy storage and a DER-based PV generation facility. Both are located at the same site, which is physically separated from the university and residential loads. While the first two scenarios are primarily simulated using the HOMER tool. Afterward, the output of HOMER was extracted and manually gave technoeconomic input (technical: PV generation, battery capacity, energy loads, amount of energy sold, and amount of energy bought at different hours; economic: cost of energy in different hours) in the MATLAB which is the TS for 2nd stage economic optimization. The TS is analysed using GA in MATLAB (GA has been utilized in this work to compare algorithm-based optimization with HOMER software-based optimization). This study integrates GA to automate load scheduling through an optimization approach. Conversely, HOMER necessitates manual hourly scheduling, which requires additional effort. GA simplifies the scheduling process by increasing efficiency, flexibility, and the ability to manage complex optimization scenarios without direct user involvement [62].

4.7. Results of the Case Study II

In this subsection economic analysis results of case study II are summarized.

Table 7 Summarized Economic Analysis results of Case Study II

Scenario	NPC (million $)	CAPEX (million $)	OPEX (million $/year)	COE ($/kWh)
FS	6.52	0.22	0.15	0.19
SS	5.38	0.51	0.112	0.13
TS	5.38	0.51	0.112	0.12

The FS has the highest COE at 0.19 $/kWh among the three scenarios. Also, it has the lowest CAPEX at 0.22 million $, as no on-site RES generation is integrated for the developed system. However, it has the highest OPEX of 0.15 million $/year and produces the highest emissions, amounting to 565.294 tons/yr. Furthermore, energy sales to the grid are absent, since the system does not produce any RES, so energy flows directly to the EV from the grid. Indeed, 894.453 MWh of energy is bought from the grid. However, this scenario has the highest NPC 6.52 million $, among the 3 scenarios [62].

The SS has the lowest NPC, 5.38 million $, among the 3 scenarios. Also, it has a COE of 0.113 $/kWh and CAPEX of 0.51 million $. However, this SS's OPEX is 0.112 million $/year, which is comparatively lower than the FS. SS presents a strategic advantage as it integrates RES, enhancing the profitability and sustainability of the EVCS. A total of 231.645

MWh of energy is sold to the grid with a RESFr of 34.6%. Consequently, energy purchases are reduced to 726.024 MWh. Moreover, CO_2 emissions are lower than in the FS, amounting to 458.847tons/yr [62].

Using the SS output from HOMER, we provided inputs to TS for cost optimization. In TS, our focus was on reducing COE and overall energy bills through GA within a VPP framework. In the initial EV charging configuration, EVs were assumed to charge at maximum power starting at 09:00 until fully charged. Under FS, the daily energy bill is 49.02 $/day. GA then rescheduled the EV load across various hours to reduce energy bill and COE [62].

An analysis of the two case studies reveals significant differences. In Case Study I, the use of renewable-powered EVCSs was effective in reducing energy costs and emissions. However, the first case only utilized one-step optimization, whereas Case Study II employed two-step optimization, which resulted in a lower energy bill compared to Case Study I. Additionally, Case Study II incorporates a VPP with the building community, which provides extra flexibility to ECs. The primary conclusion is that both of these case studies assist in reducing COE and energy bills, which can be replicated in ECs, particularly when combined with advanced management strategies, such as VPP, with the methodology developed during our analysis.

In the future, other mathematical based optimizations, such as ant colony optimization, can be utilized to schedule the loads, make the optimization stronger, and compare with current results.

5. Contribution to the WP objectives

The research carried out by ESR15 and ESR14 contributes directly to the objectives of WP5, which focus on advancing green economy models and management systems, and on coordinating research and implementation of BMs within collaborative RES, microgrids, and energy management. Both ESRs have specifically addressed the role of ECs as legal entities capable of developing a range of BMs related to decentralized energy production and consumption. ECs not only generate RES and inject them into the grid, but also provide additional services, including flexibility, e-mobility, and storage. The work of ESR14 and ESR15 consolidates current knowledge on ECs, expands understanding of their BM potential, and proposes pathways to enhance services such as EVCS.

ESR15's contribution focuses on mapping the academic debate and identifying research gaps. Through a bibliometric literature review, ESR15 clarified the evolution of the EC concept, structured existing research areas, and highlighted three major domains: the energy transition, technologies, and models. Within these domains, gaps were identified, particularly in relation to EC BMs. Building on this, ESR15 developed an analytical framework tailored to ECs, structured across five dimensions (value proposition, value creation, main functions, membership, and governance). This framework led to the identification of four archetypes of EC BMs: self-consumption, third-party, aggregator, and integrated services and e-mobility. The framework provides a systematic approach to analysing how ECs create, deliver, and capture value—economic, social, and environmental—and is aligned with WP5's goals of fostering innovative, sustainable BMs for distributed EES. The findings have academic and policy relevance: policymakers may, for instance, see self-consumption as a tool against energy poverty, while the aggregator model can address grid imbalances and flexibility needs. The results also support EC managers and market actors in designing tailored solutions.

ESR14 advanced the WP5 objectives by developing methodologies to optimise COE and GHG emissions, with a specific focus on EVCS as a service for ECs. The first outcome was a techno-economic analysis conducted on a university campus case study, demonstrating how optimisation methods can reduce COE and emissions for end-users. This provides public and private stakeholders with a framework to assess the feasibility and long-term sustainability of EVCS in community settings. A second outcome expanded this approach to both a university and a building community test case. Here, ESR14 developed a mathematical optimisation model using genetic algorithms and HOMER software to simulate the integration of EVCS, local RES generation, and storage within a VPP framework. The analysis demonstrated improvements in energy management, cost reduction, and emission abatement, while introducing innovative services for EC users. These techno-economic feasibility studies underline the role of RES-powered EVCS as an innovative service that can enhance self-consumption, enable storage and flexibility solutions (including V2G), and reduce carbon emissions.

Together, these insights strengthen the evidence base for BM innovation under WP5. Overall, Deliverable D5.3 integrates the work of both ESRs, moving from literature-based insights to validation through techno-economic feasibility studies. It demonstrates how EVCS can evolve into viable services for end-users, especially within ECs, while also creating opportunities for investors and other stakeholders to engage in sustainable energy markets. The results highlight EVCS as a catalyst for innovative BMs and services that advance the growth and sustainability of distributed EES.

6. Conclusions

D5.3 analysed market solutions and BMs to support the growth and sustainability of distributed EES within WP5. The work focused on ECs as key organisational forms to empower citizens and local actors in energy production, consumption, and management. ESR15 mapped the academic debate through a bibliometric review, identifying three main research areas (energy transition, technologies, and models) and highlighting gaps, particularly in EC BMs. Building on this, ESR15 developed an analytical framework that led to four EC BM archetypes (self-consumption, third-party, aggregator, integrated services and e-mobility), clarifying how ECs create, deliver, and capture value. ESR14 complemented this work with techno-economic analyses of RES-powered EVCS, applied to university and community test cases. The studies demonstrated the potential of EVCS to reduce COE and GHG emissions while providing innovative services for EC users. From these results, several lessons can be drawn. First, EC BMs are still low explored in the literature, and the analytical framework developed by ESR15 provides a solid basis for future categorisation and comparative research. Second, the viability of RES-powered EVCS highlights the importance of integrating mobility and building energy systems at community scale, showing that e-mobility can be more than a technological add-on: it can be a central service for ECs. Third, both strands of research demonstrate the value of combining conceptual and techno-economic approaches, bridging theory and practice in the development of innovative BMs. Looking ahead, further research should deepen the empirical validation of EC BM archetypes through surveys, interviews, and case studies across different socio-technical contexts. There is also a need to explore how ECs can integrate new services such as EVCS into viable market models that balance economic sustainability with social inclusion, for instance addressing energy poverty. Finally, future work should examine the role of regulatory frameworks and policy design in scaling up ECs and supporting their integration into broader energy markets. Overall, the lesson learnt is that ECs have the potential to become central actors in the transition toward sustainable and decentralised energy systems. By adopting innovative BMs and integrating services such as EVCS, they can simultaneously enhance local energy independence, deliver environmental benefits, and create new socio-economic opportunities for their members and beyond.

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