European Commission

bridge

Multi-energy grid planning for energy islands

Case study #7

June - 2023

AUTHORS

Athanase Vafeas, Dowel Innovation

Clémentine Coujard, *Dowel Innovation*

Stéphanie Petit, *Dowel Innovation*

SUPPORT FROM THE BRIDGE SECRETARIAT

Martin Bracken, CLERENS, BRIDGE Secretariat

Niclette Kampata, ZABALA, BRIDGE Secretariat

Marcos Jareño, ZABALA, BRIDGE Secretariat

Agnieszka Gierej, ZABALA, BRIDGE Secretariat

ACKNOWLEDGEMENTS

The editors would like to acknowledge the valuable inputs received from the projects' coordinators and partners.

EUROPEAN COMMISSION

Directorate-General for Energy
Directorate B – Just Transition, Consumers, Energy Efficiency and Innovation Unit B5 – Innovation, Research, Digitalisation, Competitiveness

Contact: Mugurel-George Păunescu

E-mail: mugurel-george.paunescu@ec.europa.eu

European Commission

B-1049 Brussels

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Directorate General for Energy 2023

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1. Multi-energy planning and digitalisation to support decarbonising energy islands

1.1. Context

The transition to a “Carbon neutral Europe in 2050” imposes deep changes in energy systems: increased electrification and digitalisation, further renewable energy integration in a context of climatic and societal resilience while ensuring energy affordability and security of supply, which creates increased flexibility needs for system operators to fulfil their missions. In parallel the rapid growth of renewable energy production offers new opportunities for decarbonising local energy systems and challenges for their smooth integration. New approaches on network architecture and planning considering local energy systems with multiple energy vectors, combined with the possibilities opened by the Energy Communities can contribute to this challenge.

1.2. Benefits

Digitalisation and storage of electricity in all energy vectors (storing electricity, heating and cooling, water, waste, hydrogen, etc.) are potential opportunities for distribution grid planning, especially for the ones considered as “energy islands”. Integrated local energy systems are explored by R&I projects deploying a wide spectrum of demonstration pilots to be scaled-up and replicated in other energy, grid, and cultural contexts.

Synergies between energy vectors could create new flexibility options for system operators in these integrated local energy systems. Ability to provide flexibility in a reliable and cost-effective manner will foster integration of renewable energy and support decarbonisation. This might offer cost-efficient alternative to building new grid elements in a context of possibly adverse public opinion.

2. Pending challenges

Planning distribution grid while fully exploiting integrated local energy systems and new cross-sector or cross-vector flexibilities implies to answer to the following questions:

- *Which local integrated and coupling solutions are relevant for a local energy generation, distribution, and consumptions context? Which tool can facilitate their planning?*
- *How to leverage on Energy Communities to make new business cases, and create economically attractive conditions for local energy sources and demand response to engage stakeholders over the long run?*
- *How to replicate elsewhere the findings and insights gained from local demonstration pilots?*

The present document illustrates how some recent projects in the BRIDGE initiative contributed to addressing these intertwined challenges.

3. Paving the way for decarbonised energy islands

Three building blocks of knowledge are proposed and detailed in the next chapters:

- **Robust, locally adapted, validated integrated solutions for decarbonising energy islands**. All four characteristics constitute the criteria proving the locally created value through exploitation of flexibility synergies from energy vector coupling on a local base (see chapter 3)
- **Leveraging on energy communities,** a key tool for engaging stakeholders over the long run (see chapter 4)
- **Increasing momentum through scaling up and replication:** designing innovation programmes from project recommendations on local integrated multi-energy systems (see chapter 5).

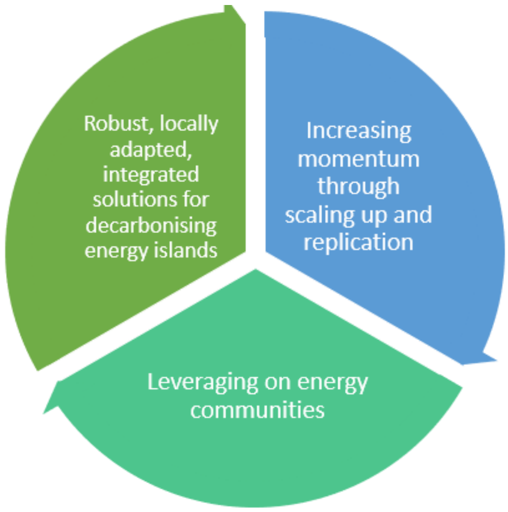


Figure 1: The three building blocks to multi-energy planning for energy islands

This case study focuses on six H2020 projects that address those buildings blocks complementarily. All projects have been awarded in the call topic 2018-LC-SC3-ES-3-2018-2020 Integrated local energy systems (energy islands):

Jan 2019 – April 2022

Merlon: Integrated Modular Energy Systems and Local Flexibility Trading for Neural Energy Islands, coordinated by HYPERTECH (CHAIPERTEK) ANONYMOS VIOMICHANIKI EMPORIKI ETAIREIA PLIROFORIKIS KAI NEON TECHNOLOGION (Greece).

Nov 2018 – Oct 2022

MUSE GRIDS: Multi Utilities Smart Energy GRIDS, coordinated by RINA CONSULTING SPA (Italy).

May 2019 – Oct 2022

IELECTRIX: Indian and European Local Energy Communities for Renewable Integration and the Energy Transition, coordinated by ENEDIS (France).

Dec 2018 – Nov 2022

E-LAND: Integrated multi-vector management system for Energy isLANDs, coordinated by UNIVERSITAT DE GIRONA (Spain).

Nov 2018 – Oct 2022

COMPILE: Integrating community power in energy islands, coordinated by UNIVERZA V LJUBLJANI (Slovenia).

May 2019 – Oct 2022

RENAISSANCE: RENewAble Integration and SuStainAbility iN energy CommunitiEs, coordinated by VRIJE UNIVERSITEIT BRUSSEL (Belgium).

4. Robust, locally adapted, validated, integrated solutions for decarbonising energy islands

This section deals with local solutions for decarbonising weakly connected areas implemented by the six considered projects and the tools in support to planners and operators. Such solutions encompass technical and non-technical features and are designed for local energy grids in urban, peri-urban, and rural areas. Typical local energy systems are isolated villages, rural areas with non-existing (or weak) grid connections, small cities, and urban districts.

4.1. The local context determines potential combinations of vectors, solutions, and tools to optimise a local energy island: a wide representation of local configurations is explored by demonstration pilots

- The design of **theoretical multi-vector energy components** (generation and demand) shall be built upon the needs of non-regulated stakeholders while being compliant with the regulated stakeholders' missions: demonstration pilots deployed according to the local configurations have been implemented by **all projects** for validation purposes of innovative tools or concepts according to predefined experimentation protocols[1].
- The **six considered Bridge projects amount to a total of 23 pilots' demonstrations implemented in 12 EU Members States** as well as in Norway and India. They cover a wide range of flexibility tools, resources, and energy vectors, as well as specific grid and energy consumption contexts in rural, urban and industrial environment.

Table 1: Overview of demonstration pilots (compilation from projects)

Project	Demonstration pilots in regions	Type
MERLON	2 pilots in Austria and Spain	Strem (AT) battery energy system to unlock further RES deployment in an area with weak interconnection with the overlay network in Strem city; Crevillent EC (ES): a LEC (local energy community) operating RES & distribution grid; both demonstration pilots showcased integrated local energy management system for distribution grid operation in high renewable scenarios with active demand and grid-scale storage.
MUSE GRIDS	2 large scale pilots in Italy and Belgium	Oud-Heverlee (B): neighbourhood strategy for flexibility and grid balancing (LEC): how to interact with local grids? Osimo (I): which interaction among several energy networks for maximising efficiency, reducing losses and reducing CO2 emissions.

[1] see for example the 12 Use Cases detailed according to a common template in MERLON deliverable D3.1 and D3.3 for the MERLON Performance Measurement and Verification Methodology (PMV). See also the 3 HLUC (high level use cases) and 12 PUC (primary use cases) defined by E-LAND in its D3.2 Functional and operational requirements and COMPILE D2.1 LES: Operational requirements, use cases and KPIs including 4 HLO and 7 UCs.

IELECTRIX	5 pilots (in Austria, Germany, Hungary, India)	Demonstrators were coordinated by DSOs implementing embedded electric island systems in Austria, Germany, and Hungary and an urban microgrid in Delhi, India with among others, findings on the design of DR with 24 hours ahead signals sent to the consumers and continuous monitoring of their engagement.
E-LAND	5 pilots (Norway, Romania, Spain, India)	Energy communities/pilots cover a wide diversity of types: an industrial harbour (Fredrikstad, Norway), the university campus (Targoviste, Romania), a technology park (Huesca, Spain), the industrial metropolitan (Delhi, India) and a residential township (Auroville, India).
COMPILE	5 pilots validating tools for empowering local energy systems in Slovenia, Spain, Croatia, Portugal and Greece.	Energy communities/pilots include urban to rural townships, technology park, residential areas: Luče, (SI), Crevillent (ES), Križevci (HR), Lisbon (PT), Rafina (GR). Pilots cover both the creation and running of energy communities, as well as technical solutions for the operation and management of local energy systems.
RENAISSANCE	4 LEC pilots for replication in Spain, Belgium, Greece and the Netherlands[2]	Sites represent different end-user groups, integrate different combinations of energy vectors and face diverse challenges. Located at: Manzaneda (SP), Jette, Brussels Health Campus (B), Kimmeria student campus (GR), Eemnes (NL). Each site developed its own approach for creating or enhancing a LEC.
All 6 projects	23 pilots in 14 countries	19 pilots deployed in 12 EU Member States[3] plus 4 pilots in Norway, India.

- The 23 demonstrations explore technical, business, socio-acceptance, regulatory features on diverse paths for integration of renewable energy into local energy systems and their decarbonisation. **Pilots start with the local analysis and formulating recommendations for wider deployment or replication of pilots** (see illustration in section 5.3).

- All tools and demo-tested solutions contribute to increased share of renewables, higher energy efficiency of the local energy system and aim at ensuring a high replicability potential.

4.2. Combination of potential designed solutions validated on actual cases, requires fitting simultaneously to technical and non-technical prerequisites, at various time horizons

- A consensual finding emerges from the considered projects: the design of a future smart local energy system requires higher flexibility level for the final energy use. Since more renewable implies more

[2] 10 replication sites testing replicability and scalability of RENAISSANCE tools were also deployed in Italy, Spain, Poland, India, Uganda, Argentina, Colombia, Chile.
[3] Austria, Spain, Italy, Belgium, Germany, Hungary, Romania, Slovenia, Croatia, Portugal, Greece, Netherlands.

uncertainty, the design (planning) and operations of the future local energy system are impacted, and **a proper consideration of the consumer side is required**.

- Capturing the flexibility on the energy use can be achieved by more sector integration and more citizen engagement in flexibility programmes (e.g., through pertinent use cases such as aggregation and the support of local authorities in **MERLON** and **E-LAND**)[4]. In **MUSE GRIDS** the pilot in the Italian city of OSIMO includes several energy networks (gas, electricity, district heating and water network) and many vectors and technologies (liquid biomass, biogas, PV, mini hydro, heat, pumping stations).

- Local energy planners and local policy makers need **planning tools analysing and combining various emerging technologies** such as storage and EVs. At the planning stage, the technical design of a coupling and synergies among energy vectors, storage and electromobility requires an anticipation of future energy consumption at the local level, of the ever-increasing electrification end uses (e.g., electromobility, desalination, heat pumps, etc.), and more generally of the future deployment locally of renewable generation. **This analysis of possible energy technology combinations requires to consider the non-technical constraints impacting the local energy system**. This is usually carried out in the preliminary tasks of each project[5].

- Pilots' demonstrations constitute a key mean for validating, at a local scale, the energy and flexibility projection models and the pertinence of energy vectors coupling, for validating technical components for operation, for assessing the response of citizens to flexibility and demand response programs and their sensitivity to incentives.

- All studied projects tested in their demonstration new tools supporting planning and operation of local energy systems. **An overview of local planning tools' characteristics has been compiled in Table 2.** They have been clustered according to challenges a pilot designer might face: technical and non-technical constraints (in rows in the table below), at different time-horizons (in columns).

- Hence, we observe from the pilots that **a modular approach for the design of pilots** is recognised as efficient (for the demonstration itself) and promising (for future replications). Another point that emerges is that **pilots' efficiency is further increased when combining numerical approaches and locally deployed experimentations**. For example, **MERLON** project developed in its WP5 Simulation-Based ILES Optimised Planning and Sizing Module deliverables[6] or the use of the RENERGISE tool combined to the MAMCA methodology for the development of energy communities of different types in **RENAISSANCE** project[7]. **MUSE GRIDS** proposed four virtual demo sites and other five replication cities (Riga (Latvia), Pesaro (Italy), Constanta (Romania), Porto (Portugal) and Cologne (Germany)) for the sake of MUSEGRIDS replication in other European and extra European contexts.

Table 2: Planning tools characteristics per type of challenges (synthesis from projects)

Typical challenges faced by a designer of a demonstration	**Complexities related to the pilot in its current and future use and options from the pilot designer perspective**	
	Current and local use:	**Future and wider use:**

[4] see for example the MERLON deliverable D10.1 Definition of MERLON Business Models for ILES and Flexibility Markets, the MERLON D3.1 and E-LAND D3.2 and COMPILE D7.1 Business Models for Energy Communities.
[5] see for example MUSE GRIDS D1.1 "Catalogue for technologies that enable grid interactions"; the pilot sites requirements in RENAISSANCE D2.2, COMPILE D2.1 "LES: Operational requirements, use cases and KPIs") or in ad hoc regulatory analyses (e.g., RENAISSANCE D6.5 Regulatory Barrier analysis, COMPILE D2.3 "Regulatory frameworks for EnC for pilot site countries – HR, ES, GR, PT, SI.
[6] see D5.1 on models and simulation scenarios; D5.2 MERLON planning and optimisation algorithms under demand and generation evolution); D5.3 MERLON Simulation-based Planning and Sizing Module
[7] See D6.3 Report on replication validation.

pilot for a local energy system	Directly for the physical implementation of a demo-pilot (in the project)	Anticipating the future design of the local energy system (the exploitation of the demo project results: elsewhere or wider)
Technical relevance: Selecting a combination among a multiplicity of local building blocks of a delimited smart energy system	- Technically, each technical component, offers its own theoretical 'flexibility signature', - which requires first to be modelled as a unit component or in combination in a given local context […]	- Modularity of building blocks. - Interoperability to standards-based legacy systems. - Hybridisation of numerical models and demonstration results enables valuable projections.
Non-technical constraints: Addressing simultaneously the multiplicity of stakeholders' constraints as prerequisites for the pilots	- […] and then to be proof-tested in a given local context with actual energy actors, physical infrastructures and generally limited flexibility margins for the demonstration phase with respect to regulation[8].	- Customisation and expandability facility. - Scalability and replicability analysis. Existence of documented demonstration returns of experience from pilots. - Virtual Demo sites. - Recommendations for future pilot designers and recommendations for regulation.

The two following sections depict some of the innovative tools developed by the six projects and their features on the initial analysis and planning (section 4.3) or for local energy system operations (section 4.4), having in mind that some of the tools have been developed to address both uses.

4.3. Demo-tested technical components include tools for analysis and combination of multiple energy vectors in a local, thus delimited system […]

- The **RENAISSANCE** project developed an optimisation tool (RENERGISE multi-vector optimisation tool) for the preliminary configuration of collective energy systems fed by real-time data and connecting multiple energy vectors, tool that was demonstrated in the ten RENAISSANCE replication pilots. The tool is intended for rough estimations[9] that come at hand as a decision-making tool before more operational phases.

- The **COMPILE** project developed a set of interoperable tools enabling co-optimisation of different technologies and energy vectors to better manage consumption, production, stored energy from the user perspective. The perspective of network operators or community leaders was addressed by the ComPilot digital platform developed by the project. This tool allows the creation of Virtual Social Energy Communities and help communities managing their operation.

- The open-source Multi-Vector Simulator developed by the **E-LAND** project enables the configuration of the multi-vector energy systems and provides optimal capacities and allocation to project sites. It also facilitates the performance validation (economic and technical). Results show that local renewable generation is able

8 except if regulatory sandboxes under conditions are allowed
9 The tool compares the total electricity import and export from and to the grid, the self-consumption and self-sufficiency ratio, and the total cost, net of investment and energy import costs.

to cover higher fraction coverage of energy demand. As a long-term the Investment Planning Tool for sector-coupled energy system is complemented by an Energy Planning Application[10] to guide the end user through system design, data input, simulation and optimisation results, including economical, technical and dispatch information.

- The **IELECTRIX** project developed for the German demonstration an IP tool (IP refers to Investment Postponement) that calculates investment postponement for network reinforcement measures, such as the integration of a battery in the system. The project proposed also specific forecasting modules (generation and demand) with the aim to maximise the share of local renewable generation, as well as advanced Direct Load Control developed in the Hungarian demonstrations for network congestion solving (also in support to investment postponement). The Scalability and Replicability Analysis (SRA) methodology published by the project intends to guide further use of the pilot itself or more generally other pilots when designing their own SRA.

- **MUSE GRIDS** project focuses on the local energy independency in weakly connected areas through optimised management of the production via end user-driven control strategies, smart grid functionality, storage, CHP (in Osimo, 1.2 MWe cogeneration plant serving a district heating network of 1250 users) and RES integration. Regarding planning, the project upgraded the EnergyPLAN tool into a Multiple Energy Planning Tool for districts and microgrid: the tool provides an assessment framework to help energy utilities and cities make local integrated energy planning decisions on their future energy mix and investments, in correlation with national strategies and local RES potential and energy demand projections[11].

- The **E-LAND** toolbox was designed according to principles securing further exploitation at a wider extent: modular, customisable, interoperable with existing systems, able to host new tools. More specifically two project results must be highlighted: (i) Common Impact model allows to design the local energy solution in a way that it is compatible with local values and priorities (ii) an approach to build Multi Vector Energy System business models for wide-scale replication and fitting to citizen acceptation criteria. Last, the replication toolkit compiles useful insights for replication[12] ().

4.4. […] and tools to optimally integrate and control multiple energy vectors in joint operations for decarbonisation and energy savings

- Tools and technical solutions developed and tested in the different pilots' demonstrations include Energy Management Systems, forecasting modules able to predict flexibility, control systems / control strategies, user-friendly interfaces for the flexibility providers and users.

- **MERLON** used a modular approach for the design of its ILESEM (Integrated local energy management system) that performs multi-level optimisation while enabling the realisation of novel business cases. An Integrated local energy system (ILES) enabled by the MERLON solution could be formed to offer a reliable supply to a district and provide some virtual-power-plant capabilities to the utilities. It constitutes a solution to support distribution grid operation in a high-renewable scenario, putting prosumers at the center. Several results of MERLON offer replicable solutions for operational optimisation of local energy systems with high shares of renewables.

- **MUSE GRIDS** project demonstrated how multi-objective controllers can optimise energy grid operations in a multi-energy context. The first-of-its-kind multi-energy DSM (Demand Side Management), an integrated

[10] Access: Energy Planning Application (rl-institut.de); GitHub: GitHub - isichos/epa: Energy Planning Application
[11] The tool is available at https://www.energyplan.eu/musetool/
[12] see D6.3 Toolbox description and Replication guidelines

single controller dealing with multiple energy systems/assets and demands towards OPEX minimization, enabling the integration of innovative flexibility assets for the creation of local energy communities. The multiple Energy Planning Tool for Districts and Microgrids is another one-of-a-kind innovation that has been replicated in the Israeli virtual demo and five replication cities. Other key innovations related to multiple energy vectors deserve to be mentioned: (i) the integration of electric vehicles and of the flexibility in a LEC brought by V2G/V2B : gradual increase in charge/discharge solve instability issues due to step loads; (ii) the impact of a neighbourhood battery installed for power quality improvement in terms of grid services and positive impacts in deferred investments; (iii) the electrification of heating delivery with increased flexibility; (iv) the smart control at the LEC level ability to predict and manage distributed loads and avoided peaks and voltage dips.

- In **E-LAND** project, two modules[13] provide optimal dispatch of controllable multi-vector energy assets in day-ahead and intraday time horizons. Overall, the E-LAND toolbox incorporates an integration solution to interface with existing Energy Management Systems to monitor and control local assets.

- The **RENAISSANCE** energy management platform dedicated for local energy systems enables consumer-centric operations, connecting multiple energy vectors in a single ICT architecture, was object of ten replications within and beyond EU. Scalability and replicability of the RENAISSANCE uses cases have been documented and constitute a solid block to transform local energy systems into fully transactive energy networks based on blockchain technology and cryptocurrencies with high social acceptance levels.

- In **COMPILE** the GridRule tool was designed to enable the actors in an energy community to operate, manage and control the local grid within the network limits while improving their flexibility, stability and security. It sets up the coordination of individual community members and enables the optimisation of the whole community's energy needs.

4.5. A collection of generic building blocks is ready for further R&I and commercial applications

- In conclusion of this section to **design future smart energy systems**, local energy planners and local policy makers need at least **three families of tools**:

    i. planning tools to project decarbonisation routes for the current energy system, by integrating new energy technologies adopted at a critical mass (e.g., storage and electric vehicles);

    ii. new modes and means for the control of energy systems combining the planned multi-vector solutions;

    iii. citizen-centred socio-economic and technology acceptance.

  At another level, new grid architecture and energy infrastructures will also be needed, which is beyond the scope of the present document[14].
- **There is no one-size-fits-all solution** but the demonstrated-prototype tools described here above cover the points (i) and (ii) in a puzzle-form of a collection of unit tools to be adopted by local energy system planners. The third point (iii) on citizen and societal is discussed in next chapter.

[13] the so-called the Energy Forecaster and the Optimal Scheduler of E-LAND project.
[14] from: Environmental Sciences Proceedings | Free Full-Text | Energy Communities: How Tools Can Facilitate Their Enhancement (mdpi.com)

5. Leveraging on Energy communities for multi-energy grid planning in energy islands

5.1. Energy Communities constitute a key tool for empowering citizens in their energy act

- Empowering citizen to play a role in the energy transition is widely recognised[15]: the concepts of energy citizens or prosumers are commonly used and associated to multiple benefits[16]. Once the energy prosumer and the legal framework are set, the concept of energy community emerges naturally in principle: it takes the form of open and voluntary co-operation where parties either own or have decision-making power in the operation of renewable energy technologies and energy services. On the legal standpoint the concept of Citizen Energy Community (CEC) and Renewable Energy Community (REC) have the legal basis of Directives[17]. The transposition process of CEC and REC definitions into national legislation is on-going[18].

- In a common paper[19] published by the **MUSE GRIDS, COMPILE, MERLON, IELECTRIX** projects, a shared vision emerges on the potentialities and barriers existing for the future role of Local Energy Communities in the energy transition in Europe. There is a consensus of these projects on the common ground for an effective decarbonisation of cities and districts in Europe: the high share of decentralised non-programmable renewable energies, which creates on the same time challenges in terms of congestion management and power quality for the local electric grid, but also create opportunities based on demo-tested solutions, these solutions addressing different technical and societal aspects of local energy communities.

- Importance of social aspects is highlighted in the same article. Availability of technical solutions is far from sufficient: citizens need indeed to be empowered to participate in flexibility programs. All projects address it: this societal readiness remains a strong requirement for in the design of future demonstration programmes[20].

- The locally delimited energy system benefits from a positive factor 'by design': the proximity factor between citizens (usually around a residential area: building, a district, a city). Gamification, serious games or local workshops (as respectively in **RENAISSANCE** or in **COMPILE** projects) are innovative approaches grounded on such local anchorage of citizens to their area.

[15] Empowering Citizens for Energy Communities, A Policy Brief from the Policy Learning Platform on Low-carbon economy November 2022, Interref Europe, European Union | European Development Fund
[16] Carbon emissions savings, access to cheaper and secure electricity for the final consumer, autonomy of supply, etc.
[17] respectively the Directive (EU) 2019/944 – Electricity Market Directive; Directive 2009/73/EC – Internal Gas Market Directive and the Directive (EU) 2018/2001 – RED II.
[18] https://www.rescoop.eu/transposition-tracker
[19] see footnote 14.
[20] For example: MERLON deliverable D9.6 MERLON Living Lab Activities Planning and Evaluation Report – Second Version details how the concept of Living Lab was implemented for the Austrian and Spanish pilots, RENAISSANCE D7.4 Report on the stakeholder engagement campaign or the COMPILE D4.4 Stakeholder guidance, the E-LAND D2.5 Common Impact Model designed to improve social acceptance and increase participation of stakeholders in the planning and operating of energy communities

5.2. Pilots and tools of the COMPILE project lay the foundations for the integration of community energy in energy islands

- **COMPILE** project show-cased the opportunities of remote areas or areas weakly connected to the grid, for decarbonisation of energy supply, community building and creating environmental and socioeconomic benefits. It developed a suite of tools to assist groups of citizens in creating, and then monitoring energy communities. The tools have then been deployed on five pilot sites.

- The four technical tools and two support tools of **COMPILE** are all interoperable and enable co-optimisation of technologies and energy vectors to better manage energy of users in a local energy context:

    - **For the creation and running of energy communities: COOLkit** is a learning tool which enables the general population to know more about the concepts and opportunities of energy communities. The **Value Tool** is a web-based simulation tool which performs economic analysis prior to PV-based energy communities to check the viability and optimise the profit. The project has also built the **Maturity Scale Framework which** provides a list of useful indicators to monitor the progress a prosperity of an Energy Communities. It is used during workshops with local community members to make them aware of the capabilities and weaknesses of their community project.

    - **For the operation and management of local energy systems: GridRule** helps actors to operate, control and manage a microgrid in a way to improve its flexibility, stability, and security. **HomeRule** is an energy building management application enhanced with new algorithms for co-optimisation of different technologies and energy vectors for energy management (users' perspective). **ComPilot** enables network operators or community leaders to monitor and manage contracts of the community. COMPILE also worked on the development of EV charging solutions and created the **EVRule** which integrates load control within HEMS (HomeRule) and demand response within Local Energy System (GridRule, ComPilot).

- Achievements in the main pilot site **Luče (SI)** in **COMPILE** consisted in the installation of additional photovoltaic capacity and a community battery able to provide power for 2-3 days increasing safety in a rural low voltage network**.** A crowdfunding approach proved to be effective for funding new photovoltaic capacity and increase self-sufficiency of a technology park, and support Energy Community operations by blockchain technologies **(Križevci, HR)**. **Crevillent (ES)** as a case of municipality grid proved to be a first-of-a-kind application innovating on the community building aspect, social cohesion, and activation of users with new smart meters and new PV roofs fully operational. Pilot site **Lisbon (PT)** addressed effectively energy poverty and vulnerable households, while in **Rafina (GR)** an energy community has been established as a cooperative and has developed a small installation of 100 kWp Photovoltaic generation.

5.3. Dedicated methodological approaches are well-fitted to address the multi-stakeholder perspective needed for energy communities

- **RENAISSANCE** project developed a multi-stakeholder analysis framework in the MAMCA methodology (Multi-Actor Multi-Criteria Analysis , source: [RENAISSANCE results slide deck - Renaissance H2020 Project (renaissance-h2020.eu)](renaissance-h2020.eu). In the energy market contexts, the MAMCA analysis is used to engage all stakeholders, including citizens, to build mutual awareness of their objectives and their often-diverging needs. It can be used to build consensus when different actors decide to cooperate in a project of energy transition and ultimately increase acceptance and uptake of new solutions. The end result of the analysis is a list of most-desired scenarios, while the know-how gained supports future collaboration in their actual implementation.

- **MAMCA** framework is a scalable and replicable approach: the process to engage stakeholders foresees for example MAMCA dedicated workshops, video interviews, layout materials in local language, onboard events, pilot site tour, explanatory video but also possibly tourist engagement as for example in the Manzaneda site (**RENAISSANCE** D7.4 Report on the stakeholder engagement campaign).

- **E-LAND** project enabled a study focusing on the particular perspective of EV drivers and assessing their willingness to accept charging. Segment likeliest to be early adopters of smart charging were identified for providers of smart charging solutions[21]. More generally the above-mentioned Common Impact Model (E-LAND D2.5, D2.4) is also addressed to understand and align views and expectations of multiple stakeholders.,

- A preprint[22] of a research article related to the Prosumer business models developed by **RENAISSANCE** project[23] is under peer review is available. It focuses on predicting acceptance and adoption of renewable energy community solutions. More specifically the prosumer psychology and analyse psycho-sociological factors intervening in acceptance processes. Five latent factors are identified: concern about environmental issues, interest in energy sharing, concern on climate change, social influence and impact on bill cost.

- On the question of social acceptance, a comprehensive framework for analysing the social acceptance of local energy solutions was developed by **MUSE GRIDS** project and tested in the two pilot cities. This framework focused on general, local, and end user acceptance, and included factors that influence social acceptance gained from literature with empirical insights gained in pilots (MUSE GRIDS D7.2 "Social Acceptance of MUSE GRIDS project outcomes starting from demo-site outcomes").

- High level of interest from a wide variety of stakeholders has been generated by already mentioned **COMPILE** Maturity Scale Framework[24]. The tool is meant to support community leaders to better understand and assess the level of development and resilience of their initiatives to market forces. Among other things, the validation of the tool showed that networks are crucial but need to be supported externally to withstand the ups and downs in the energy system.

5.4. An overview of tools to build and support energy communities has been presented in the Bridge Case study #5 on energy communities

- This Case Study #5 "Energy Communities: tools to build them and make them thrive" detailed tools dealing either with planning, optimal operation and citizen engagement developed by some R&I projects (E-LAND, COMPILE, e-neuron, Hestia, LocalRES).

[21] Merla Kubli, EV drivers' willingness to accept smart charging: Measuring preferences of potential adopters, Transportation Research Part D: Transport and Environment, Volume 109, 2022, 103396, ISSN 1361-9209, link
[22] Predicting acceptance and adoption of ... | Open Research Europe (europa.eu)
[23] RENAISSANCE: survey on renewable energies and community-based solutions - Glossy Report - Renaissance H2020 Project (renaissance-h2020.eu)
[24] COMPILE D4.2 The Community Maturity Framework.

- The take aways of this Case study#5 confirm the new thinking brought by energy communities and the necessity to consider the long run for the representation of the energy system. For tooling the integration challenges raised by energy communities require tailor-made solutions adapted to their local features and underlying energy systems and assets. Practical hints in the preparation stage of energy community were also delivered such as: the determination of level of engagement that could be achieved, the identification of local ambassadors and of core engagement groups, the delivery information modes and the importance of the necessary pedagogy through easy language: see section 5.6 of the same source for engagement recommendations and practical tips).

6. Increasing momentum through scaling-up and replication recommendations

6.1. Capitalisation effort on completed demonstration pilots, each in its local context, requires guidance and support

- All considered pilots of the six projects have proposed campaigns in response to the same EC Call on energy islands. Pilots' demonstrations differ and reflect various configurations of local energy systems. Hence weak grid areas in urban, peri urban and rural areas, in Europe and in India covered by the 23 pilots constitute a multiform set of customised configurations.

- While capitalising on the demonstrated tool validation appears relatively easy and direct, building upon the value of the knowledge produced by the demonstrations is trickier, since: immaterial, accessible through open repositories or via dissemination channels that are active during the project but might be switched off after a few months after project end. The produced knowledge often remains practically in the hands of projects and pilots' ecosystems, practically the project initiators or results' owners.

- The capitalisation effort for the community is partially undertaken at the project level, projects have to be encouraged or incentivised for that purpose. This can be done systematically or on purpose through thematic enquiries[25]. Two examples of such thematic follow which could be valuable for designer of future demonstration pilots: on practical **protocols to define and monitor performance in demonstration pilots**, and on **scaling up and replication**, a third one on value and challenges of **BESS integration experienced in real situation**.

6.2. Assessing the relevance and the performance of the tested solution requires stakeholders' agreement on performance indicators of pilots

- All considered projects defined KPIs to assess performance for the deployed pilots. Despite their diversity a set of common performance indicators emerge in a trans-project perspective.

[25] One same question to several projects, with answers analysed according to the same process.

Table 3: KPIs defined by projects in their protocol to monitor pilots' performance

Demo project	Claimed KPIs
MERLON	- Demonstrated CO2 savings, curtailment avoidance, increase in self-consumption, increase in thermal comfort, Energy cost savings, increased end-user acceptance and financial viability.
MUSE GRIDS	Decarbonization, supply/demand balancing, self-consumption increase and grid stability demonstrated through new storage systems installations, generation and demand prediction tools, smart multi-objective control for multigrid energy local system and planning tool. KPIs included: - Environmental KPIs: demonstrated CO2 savings, decrease of non-renewable energy demand, decrease of GhG emissions (GWP 100), decrease of NOx emissions, decrease of dust emissions, decrease of water demand. - Technical KPIs: energy savings, peak reduction, increase of energy production[26], integration facility of new renewable generation (via the assessment of the Hosting Capacity), a more secure and stable energy system[27], moderated energy demand[28], demand shifting and energy arbitrage. - Economic KPIs: investment deferral, CAPEX of the technologies to be deployed in the demo sites which is directly related with one of the direct impacts of MUSE GRID project, OPEX. - Social KPIs: the creation of new jobs, creation of two local energy communities, awareness and better understanding of energy system transformation, social acceptance.
IELECTRIX	- Demonstrated CO2 savings, increase in self-consumption and self-sufficiency, avoided voltage constraints, hosting network capacity improvement, peak load reduction, energy savings, network losses, investment deferral, avoided generation curtailment and islanding performance.
E-LAND	- Demonstrated viability and impact of multi-energy islands toolbox and related methods in support to decarbonisation tools.
COMPILE	The location of pilots' sites in regions with need for economic recovery stress the importance to monitor socioeconomic benefits for their roll-out: - demonstrated combination of the social tariff and REC/CSC scheme leading to higher cost savings for households in Spain and Portugal. - demonstration island-mode operation to power communication towers and fire stations, enhancing safety in case of critical weather events.
RENAISSANCE	- Demonstrated scalable and replicable approach to implement business models and technologies for local energy communities.

- **Generic performance indicators of demonstration pilots** result then directly and can be organised according to the life cycle of a demonstration, from its initial analysis and design up to the assessed value created for the local energy system and for further development: at that final stage impact analysis is carried out for the site itself (e.g., CO2 savings, energy efficiency indicators) and on a wider scale energy infrastructure, local economy, air quality).

[26] This can be assessed by means of a proxy indicator such as Reduction of RES curtailment.
[27] It can be assessed using the following proxy indicators, at least for Oud-Heverlee demo thanks to the access to the network model "number of voltage violations avoided" and "number of local grid congestions avoided".
[28] It can be assessed by calculating the reduction of energy imports from upstream the local energy community.

1. Preliminary analysis of the case: barriers and policy issue (site base)	**2. Return of experience** on the pilot demonstration (process) and on the lessons learned (insights, validated tool, etc.)	**3. Scaling-up and replication analysis: potential for SRA of a pilot**	4. A **multi stakeholders' impact analysis** of the decarbonisation solutions on the site and on a wider scale

Figure 1: Generic performance indicators emerging from demonstration projects and organised according to the four stages of a demonstration pilot from preparation to impact assessment

- **Non-technical surrounding issues** in the preliminary stage remain critical, in particular for energy communities: the regulatory analysis and the possible evolutions, the ability to connect with local stakeholders or the preparation of a robust business plan backed by data[29].
- A criterion on **the 'replication potential'** shall be a by-design constraint to regional demonstration pilots. By 'replication potential' we refer to the modalities on how to replicate the solution validated in a given local context into several different regions and energy contexts and that are acceptable by local citizens. An underlying concept is the assessment of the proximity or the similarity to the locally validated pilot.

6.3. How could a project designer secure scaling-up and replication of its pilot?

- Scalability and Replicability is systematically addressed in projects. Let's illustrate over some of them.
  - The replication process developed in the **RENAISSANCE** project lasts about 6 months and foresee 5 steps around a Multi-Actor Multi-Criteria Analysis (MAMCA, see Deliverable RENAISSANCE D6.3: from a Pre-MAMCA survey up to the MAMCA workshop and regulatory final workshop).
  - In **IELECTRIX** project scalability and replicability were in the hands of the Replicability Board and the Advisory Board of the project as described in the project newsletter N°9: a dedicated functional SRA evaluated how boundary conditions impact the demonstrations KPIs as well as the impact on regulation, stakeholders and ICT.
  - **COMPILE** recommended the methodology for creating energy communities based on the experiences from its pilot sites. The so-called roadmap[30] proposed a comprehensive set of tools developed by the project which aims to support energy community leaders, members and enthusiasts. A generic timeline with important phases of EnC projects was presented to assist with the justification and planning of new activities for EnCs. Important primary activities and aspects to consider, technical and financial variables as well as well-known administrative burdens were discussed. The methodology was applied to the case of collective self-consumption in the Greek pilot site.
  - In **MUSE GRIDS**, an early start of the replication and scalable process enabled to leverage the monitored results of demonstration activities towards guidelines redaction for future replication. The DSM tool and the MUSE GRIDS Planning Tool that were tested on the two real pilots, were validated in four virtual demo sites (e.g., in Bali Island and in the District of Barrio Belén and San Cebrián de Campos Village (Spain), in Eilat (Israel)) and in five other replication cities identified during the project (Riga (Latvia), Pesaro (Italy), Constanta (Romania), Porto (Portugal) and Cologne

[29] See RENAISSANCE: best practices in Creating an Energy Community
[30] COMPILE D7.3 Roadmap for the replication of business models and project solutions

(Germany)): the MUSE GRIDS Planning Tool provided to these cities with a new 'implementable' vision ensuring environmental and economic benefits.

- An important issue for the scaling-up of a pilot is the consideration of the DSO perspective, interaction to be anticipated.
  - **IELECTRIX** project concentrated on the essential role of the DSOs in the energy transition in implementing local solutions. Project pilots focused on the interactions between DSOs and local energy communities to integrate them into their operation. Practically this required forecasting modules (generation, mobile storage, and demand) to maximize the quantity of local consumption of RES, grid digitalisation tool. For example, the technical integration of a storage with grid-serving purposes into the grid was the object of **IELECTRIX** demonstration in Germany.
  - In **MERLON** project the DSO perspective was also addressed through a holistic digital framework that included tools for planning and operation of flexibility assets for distribution grid management. A prime example includes the new approaches for scheduling flexible resources: an optimal flexibility scheduling scheme based on convexification methods was demonstrated in the Austrian distribution network[31].
  - **COMPILE project** examined the interactions that energy communities are developing with different actors – DSO, municipalities and market actors[32]. DSO and their support were seen as a crucial factor in the development of innovative and local actors. Moreover, DSOs and energy communities should work in alignment for the energy transition towards a new system operation paradigm.

6.4. Insights from BESS integration from pilots

- The German demonstration in **IELECTRIX** showed the potential of battery storage to network congestion management: how a storage unit properly operated could have a great influence to avoid RES curtailment and to prevent grid overloads. Levels up to 20% of CO2 emissions savings by increasing self-consumption (13%) and self-sufficiency (20%) of the community have been demonstrated thanks to battery storage. The same demonstration also showed the ability of battery storage to support frequency through virtual inertia in grids with a high-RES penetration and no locally connected rotating mass: it was simulated that up to 40% Rate-of-Change of Frequency (RoCoF) is achievable through virtual inertia.

- The Austrian pilot in **IELECTRIX** demonstrated the flexibility forecasting and scheduling capabilities of multiple assets including storage (100 kWh capacity of battery, 50 kW inverter, 30 kWp PV integrated). Lessons learned on BESS integration include the importance of protective measures that need to be detailed at the connection point and according to the battery capacity, the legal boundary conditions for implementing and operating a BESS as well as the proper definition of operation modes. The same pilot also showed how the local energy system could gain in resilience thanks to the distributed reactive power control.

- In **MERLON** project, BESS flexibility was leveraged to demonstrate a 11.5% reduction in energy costs through smart charging/discharging strategies taking advantage of cheap, local and green electricity generation. IELEXTRIX and MERLON projects demonstrated how a human centric demand response framework could work in tandem with grid-scale storage by integrating prosumers with smart home equipment in network management techniques. Flexibility from residential energy assets led to about 15% of reduced energy costs for the households through smart control strategies under explicit demand response campaigns. It highlighted how a few factors are essential such as the continuous communication

[31] Flexibility Scheduling for Distribution Systems: A Case Study in Austria Da Huo, Marcos Santos, Jim McGrath, Neal Wade, David Greenwood, CIRED 2021 Conference. Link
[32] COMPILE D4.4 Stakeholder guidance.

with participants, the ability of outlining properly benefits for participants, or the easiness (plug and play) and a low level of maintenance.

- In the Spanish demonstration site of **MERLON** similar gains in terms of energy costs were reported. More specifically, the BESS there contributed directly to a 7% reduction of energy costs for the LV consumers by utilising local PV generation. Explicit demand response using household appliances (electrical domestic water heaters) led to an additional 15% of cost reduction for the homes.

- The **IELECTRIX** Hungarian demonstrations consisted in two owned battery energy storages and a Direct Load Control (DLC) system for voltage management on Medium Voltage (MV) line over two sites (respective capacity of batteries of 500 kW / 1,233 kWh in Zánka and 250 kW / 573 kWh in Dúzs, objective ending to reduce peak loads and voltage variations as well to increase RES hosting capacity and optimise RES local consumption. Voltage drops were reduced by 0.8% in Zánka site, by 1% in Dúzs demonstration. Networks conditions were improved in both sites by improved grid voltage profile and MV line load reduction. Integration of BESS on the demonstration sites highlighted the delay risks in installation by various factors: lack of local expertise from supplier, non-European suppliers, long development time of the control system, or in ICT systems connection. For DLC system integration, it was shown how challenging is to provide a control that simultaneously satisfies network need while avoid disturbing consumers and highlighted the importance to consider the seasonal update.

- The **IElectrix** Indian demonstration set up an urban low voltage microgrid connected to a MV/LV substation in New Delhi allowing the implementation of a Local Energy Community. The microgrid embeds a BESS of 200 kVA BESS allowing the electrical back-up in case of a MV grid loss. This energy community is made of a large school with 4,000 students, a community centre and several households and buildings, with 200 kWp provided by photovoltaic panels installed on the roofs of the buildings. This demonstration also implemented a demand response program, involving prosumers and consumers of the energy community.

  In this project, the BESS and all the other demonstration equipment were designed and manufactured in Europe and exported in India. Now that the basis of these technologies has been tested in a real demonstration site in India, if new projects around energy communities were to be replicated in India relying on the same technologies, it would be much more efficient and much cheaper to order the technology directly from suppliers in India, facilitating the purchasing, logistics and later maintenance of the solution.

- Battery island mode was tested in **COMPILE**: With the establishment of the Slovenian pilot site Luče, supported by the local DSO, a unique opportunity for community battery implementation was realised. This was the first large-scale project of its kind to be implemented in Slovenia's electricity network. The grid connection was weak because the local low-voltage grid was in a remote part of Slovenia and conventional grid reinforcements did not present rational measures. The implementation and advanced control of the BESS, integrated into the Luče pilot, improved grid stability, even preventing blackouts that would otherwise occur. The BESS provided the first-of-its-kind island mode operation, supplying and keeping the grid section operational in the event of a power outage.

- The **MUSE GRIDS** project in Oud-Heverlee, Belgium pilot, has made significant progress in the development of a neighbourhood battery concept. One important aspect of this progress is the upgrade of the battery energy storage system (BESS) to enhance efficiency by reducing losses and minimizing the need for thermal regulation. This was achieved by installing the BESS inside a concrete housing with improved insulation and greater thermal mass, resulting in slower temperature changes. In addition, a fire suppression system was installed inside the BESS building, further improving its safety. During the demonstration campaign, the impact of flexible assets on auto-consumption was demonstrated, with the community battery being the largest contributor to the improvement in auto-consumption rate, followed by water boilers and V2G. Flexible assets nearly doubled the auto-consumption rate, increasing it from 24% to 49%.

7. KEY TAKE AWAYS

	Section 3: Robust, locally adapted, validated, integrated solutions for decarbonising energy islands
☑	A wide spectrum of tools for integrated local energy systems in various configurations aiming to validate tools aimed for a local scaled-up use and for further replication. Demo-tested tools include energy management systems, forecasting modules able to predict flexibility, control systems / control strategies, user-friendly interfaces for the flexibility providers and users.
☑	Transversal analysis of the 19 pilots in 12 EU27 Member States, plus 4 pilots in Norway and India, highlight design features valuable for design future demonstration (e.g., KPIs, guidance on preparation and monitoring).
💬	The Common Impact Model is a tool developed within **E-LAND** project to help urban planners, energy managers, and other interested parties to design clean and local energy solutions that are compatible with local stakeholders' views, values, and priorities (E-LAND deliverable D2.5).
💬	**MUSE GRIDS** set the ground to researchers and model developers of energy system modelling tools for municipal-level energy planning[33]
💬	The modular approach used by **MERLON** project for the design of its ILESEM (Integrated local energy management system) set the basis for a solution to support distribution grid operation in a high-renewable scenario, putting prosumers at the center. Several results of MERLON offer replicable solutions for operational optimisation of local energy systems with high shares of renewables.
💬	The learnings from the **COMPILE** pilot sites have led to the creation of toolsets that have the potential to empower other communities to take on their local energy systems with large or even entire shares of renewable energy. Six COMPILE tools cover both the creation and running of energy communities, as well as technical solutions for the operation and management of local energy systems.

	Section 4: Leveraging on Energy communities for multi-energy grid planning in energy islands
☑	Energy Communities constitute a tool for empowering citizens in their energy act and prepare an effective decarbonisation of cities and districts in Europe. They require a new thinking and to consider a long-term time horizon for multiple stakeholders and not only short-term benefits.
☑	Project demonstrations address the issues of technology adoption and citizen engagement. Societal readiness remains a strong requirement for the design of future demonstration programmes dealing with energy.
☑	The locally delimited energy system benefits from a positive factor 'by design': the proximity factor between citizens. Serious games or local workshops are innovative approaches grounded on such local anchorage of citizens to their area or to their activity / community.
💬	Pilots and tools of the **COMPILE** project lay the foundations for the integration of community energy in energy islands.
💬	The university campus of Valahia University of Targoviste (UVTgv), as **E-LAND** pilot in Romania illustrated how community stakeholders can directly impact their local energy infrastructure and develop sustainable energy islands by students and staff engagements through seminars and educational materials and the support of energy management and control systems for data and insights, which replicability purposes. Similarly, the Spanish demonstration on how to establish an industrial prosumers' energy community in the WALQA technology park in North-eastern Spain provides an interesting template for replication.

[33] See Article and publication on D3.2

	More than 20 Renewable Energy Community business models have been delivered and tested with the **RENAISSANCE** tools with regulatory landscape and barriers identified. Business models including 15 different types of stakeholders directly engaged and 400+ citizens and students directly involved (RENAISSANCE results slide deck - Renaissance H2020 Project (renaissance-h2020.eu)). Scopes included the increase of RES in local grid (Manzaneda, SP), regulatory exemption to launch a prosumer-driven market (Eemnes, NL), improvement of micro-grid reliability and optimisation of demand response (Brussels, BE), Lowest-as-possible operational costs through gamification (Kimmeria, GR).

Section 5: Increasing momentum through scaling-up and replication recommendations	
	All pilots constitute fruitful knowledge blocks validating tools, and approaches for further replications.
	BESS constitute a promising solution for avoiding RES curtailment, improving the local use of energy in a community, providing flexibility to the DSO, reducing network losses, and improving quality of energy supply and grid resilience. However, implementation costs remain high, which requires a case-by-case assessment in a given regulatory condition to evaluate the potential benefits (**IELECTRIX**)
	Practical protocols to define and monitor performance in demonstration pilots emerge from the various pilots as well as generic indicators, which offers guidance for future demonstration pilot designers.

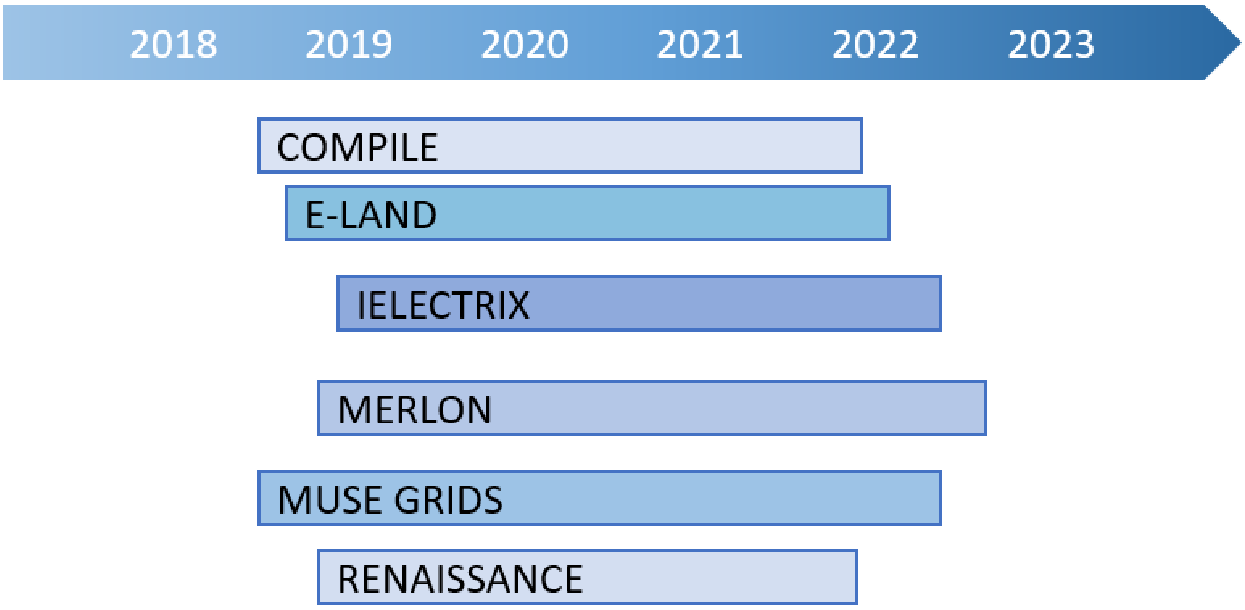
Legend of pictograms:

statement from projects' results and findings

recommendation formulated by the projects (directly or through the Bridge initiative).

8. References

Timeline of the projects studied



Projects information

Bridge project	Website and title	Contact
MERLON	Merlon: Integrated Modular Energy Systems and Local Flexibility Trading for Neural Energy Islands	HYPERTECH, Greece
MUSE GRIDS	MUSE GRIDS: Multi Utilities Smart Energy GRIDS	RINA Consulting Spa, Italy
IElectrix	IElectrix: Indian and European Local Energy CommuniTies for Renewable Integration and the Energy Transition	ENEDIS, France
E-LAND	E-LAND: Integrated multi-vector management system for Energy isLANDs	University of Girona, Italy
Compile	COMPILE: Integrating community power in energy islands	University of Ljubljana, Slovenia
Renaissance	RENAISSANCE: RENewAble Integration and SuStainAbility iN energy CommunitiEs	Vrije Brussel University, Belgium

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This brochure is financed by the European Commission and developed by DOWEL Innovation.

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