



Report on data bases development (D2.3)

Marta Carbonés
Chiara Ippoliti
Isaac Farradellas
Harold del Castillo
Camila Álvarez
Oriol Biosca
Andreu Ulled



CC BY-NC: This license allows users to distribute, remix, adapt, and build upon the material in any medium or format for non-commercial purposes only, and only so long as attribution is given to the creator.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No GA 101061051. The work developed under this project is also supported by Innovate UK through the Horizon Europe Guarantee scheme. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or Innovate UK. Neither the European Union nor the granting authority can be held responsible for them.



**Funded by
the European Union**



**UK Research
and Innovation**



Report on data bases development (D2.3)

Report on data use, availability, innovation, and structuring within the RUSTIK project, based on European indicators and 14 Living Lab experiments. This report presents the advances of the RUSTIK Viewer, analyses how data captures the five rural functions (ecological services; innovative infrastructures and services; land-based products; diversified production systems; and social capital and cultural assets), compares innovative methods applied locally, and introduces a pilot agent-based model for exploring land-use scenarios in rural contexts.

Deliverable Number	WP / T
--------------------	--------

D 2.3	WP 2
-------	------

Lead Beneficiary	Deliverable Author(s)
------------------	-----------------------

MCRIT	Marta Carbonés; Chiara Ippoliti; Isaac Farradellas; Harold del Castillo; Camila Álvarez; Oriol Biosca; Andreu Ulled
-------	---

Beneficiaries	Deliverable Co-Author(s)
---------------	--------------------------

—	—
---	---

Planned Delivery Date	Actual Delivery Date
-----------------------	----------------------

30.06.2025	30.06.2025
------------	------------

Type of deliverable	R	Document, report (excluding periodic and final reports)	x
	DATA	Data sets, microdata, etc.	
	DMP	Data management plan	

Dissemination level	PU	Public, fully open, e.g. web (Deliverables flagged as public will be automatically published in CORDIS project's page)	x
	SEN	Sensitive, limited under the conditions of the Grant Agreement	





INDEX

1.	Introduction and Approach of the Report.....	5
2.	Living Lab Data Experiments.....	7
2.1.	Aim.....	7
2.2.	Background. Review of data interests by Living Labs.....	7
2.3.	Comparative analysis of data experiments, sources and methods	9
2.4.	Identified challenges related to data collection	16
2.5.	Reflections on data sources, methods and tools.....	18
2.6.	RUSTIK best practices for overcoming challenges.....	20
2.7.	Lessons learned: data availability and capacities gaps, and strategies to address them	23
3.	RUSTIK Database and RUSTIK Rural Functions	26
3.1.	Aim.....	26
3.2.	Methodology	27
3.3.	Results.....	28
4.	Database Development and Integration in the RUSTIK Viewer.....	42
4.1.	Aim.....	42
4.2.	Conceptualization of the RUSTIK Viewer.....	43
4.3.	Status of European database integration	44
4.4.	Status of Living Lab databases integration.....	46
4.5.	Next Steps	49
5.	Land-use Agent-based Model: testing the RUSTIK database with selected Living Labs	52
5.1.	Aim.....	52
5.2.	Background of Agent-based Models (ABM).....	55
5.3.	Model Inputs.....	57
5.4.	Model Operation	60
5.5.	Model Outputs	63
5.6.	Interpretation and Use.....	67
5.7.	Potential contributions of Machine Learning to the Agent-based Modelling approach.....	68
5.8.	Assessing the Replicability Potential of the Agent-based Model Across Living Labs	70
6.	Final Conclusions.....	81





TABLES

Table 1. Comparative overview of experiment objectives, data sources, methodologies, innovations, and challenges across the different Living Labs.....	10
Table 2. Mapping of data issues, strategic responses, and implementation cases by topic.	23
Table 3. European and LL indicators related to “Provision of ecosystem services” function.....	30
Table 4. European and LL indicators related to “Innovative infrastructures and services” function.....	32
Table 5. European and living labs indicators related to “Provision of high-quality and accessible land-based products” function.	34
Table 6. European and living labs indicators related to “Distributed and diversified production systems” function.	38
Table 7. European and LL indicators related to “Social capital / cultural assets & cooperative institutions” function.....	40
Table 8. <i>Sections for the RUSTIK Transitions in the European Core</i>	44
Table 9. ABM Platforms	55
Table 10. Summary of Living Lab inputs on analytical and policy relevance of the model	76

FIGURES

Figure 1. Conceptualization of the RUSTIK Viewer, and structure of databases.....	43
Figure 2. Local Data from Living Labs	48
Figure 3. Roadmap for RUSTIK Viewer Development.....	51
Figure 4. RUSTIK Land-use Agent-based Model. Front Page.....	52
Figure 5. Inputs of the model.....	52
Figure 6. Capacities	57
Figure 7. Initial Land Occupation	58
Figure 8. Attractivities.....	58
Figure 9. Interdependence Factors.....	59
Figure 10. Polya Process Algorithm	62
Figure 11. Table of Results for Industrial Sector	63
Figure 12. Table of Results for Residential Sector	64
Figure 13. Table of Results for Agricultural Sector	64
Figure 14. Table of Results for Forestry Sector	65
Figure 15. Summary Table of Results.....	65
Figure 16. Summary Table and Graphs for Land Use Changes.....	66
Figure 17. How familiar are you with agent-based modelling? (Survey: 13 answers).....	71
Figure 18. How familiar are you with land-use modelling? (Survey: 13 answers)	72
Figure 19. Have you ever used simulation models to forecast rural change in your Living Lab? (Survey: 13 answers)	73
Figure 20. How useful would be a user-friendly tool (MS Excel) for your local context? (Survey: 13 answers).....	79
Figure 21. How feasible would be adapting and/or developing an agent-based model based or inspired in the RUSTIK pilot model on your Living Lab? (Survey: 13 answers)	80





1. Introduction and Approach of the Report

This report, *Deliverable 2.3 Report on data bases development*, provides a comprehensive analysis of data use, availability, innovation, and structuring within the RUSTIK project, both at the European level and across the 14 Living Labs.

The report is structured around two complementary scales of analysis. At the European level, it presents the core database of over 100 indicators and evaluates their capacity to reflect the five rural functions identified in the RUSTIK framework (ecological services; innovative infrastructures and services; land-based products; diversified production systems; and social capital and cultural assets). This analysis shows both the strengths and the gaps of current pan-European data systems in capturing the complexity of rural territories.

At the Living Lab level, the report draws on the results of the experiments carried out locally to explore innovative methods for data collection, integration, and use. A comparative assessment is provided across all Living Labs, focusing on the objectives, sources, tools, and innovative mechanisms underpinning each data experiment. Special attention is given to the role of novel techniques—such as participatory GIS, AI-powered dashboards, and web scraping—as enablers of localized, evidence-based policymaking.

The report also presents the pilot application of an agent-based land-use model, tested using data from one of the Living Labs. The model is designed to explore spatial development trajectories and policy scenarios in rural contexts with limited data availability. Based on its implementation, the report examines the feasibility of replication across other Living Labs and gathers their feedback regarding its potential use in territorial planning and policies design.

The report is structured around four main chapters:

- The first chapter provides a presentation of **the data experiments** conducted by the Living Labs during Cycle 2: *Experimentation*. Building on the findings of Deliverable D2.1, this section establishes a baseline to understand both the existing data capacities and limitations within the Living Labs—effectively setting the stage for the experimental phase. Then, based on the [D3.2 Second Living Labs Report](#), it analyses the goals, data sources, methods, and levels of innovation achieved. A comparative analysis across the fourteen Living Labs distils common patterns, innovative practices, and key lessons that can inform future efforts.
- The second chapter presents an analytical framework designed to **assess the five rural functions**. It uses indicators from the RUSTIK database—at both European and local levels—as inputs for this evaluation. The section highlights how effectively the database captures the multiple dimensions of rural systems, revealing both strengths and existing data gaps.
- Chapter three turns to the **RUSTIK Viewer and database** and describes the ongoing process of data integration into the interactive viewer. It outlines the system's current functionalities, the types of data included (approximately 200 indicators, half of them at European level and half of them alongside a wide range of local layers sourced by the Living Labs), and the next steps planned to improve dissemination of the Viewer and transferability and maintenance.
- Finally, the fourth chapter presents an **application of an agent-based land-use simulation model**. The model is developed as a Pilot initiative using Sant Miquel de Balenyà Living Lab data, to assess potential support to land use planning. The model allows for the exploration





of spatial change scenarios and serves as a practical and accessible tool for territorial planning and policy design in data-scarce rural contexts. Outcomes from discussions with RUSTIK Living Labs on the Pilot's findings are examined to identify which elements may be of broader interest or generalizable in other Living Labs, for replication in different rural contexts.





2. Living Lab Data Experiments

2.1. Aim

This section presents an assessment of the data experimentation activities conducted during Cycle 2: *Experimenting*. Specifically, it analyses the processes related to data experimentation implemented by the Living Labs participating in the project. The analysis is based on a review of the Second Living Lab Reports and is enriched with a comparative perspective.

The objective is to identify common patterns, methodological approaches, and challenges encountered during the experiments, as well as to understand the varying levels of data readiness, usage, and innovation capacity across the different Living Labs.

2.2. Background. Review of data interests by Living Labs

Before launching the Living Lab Data Experiments, an evaluation was conducted across the 14 Living Labs in December 2023 (Cycle 1: *Planning and Possibilities*) to identify key topics of interest, assess data availability, and highlight existing gaps. This assessment provided a baseline to understand regional strengths and limitations in data collection, accessibility, and usability.

Among the most **relevant topics** for Living Labs, population ageing, job opportunities, and social cohesion emerged as primary concerns, followed by issues such as social inclusion, innovation support, and governance. In contrast, issues related to housing, healthcare services, and education were considered less critical. Specific regional priorities also surfaced; for instance, the Austrian Living Lab emphasized the importance of studying vacancy rates, affordable housing, remote work, quality of life, and local economic development, reflecting its focus on demographic and economic shifts.

In terms of **data availability**, eight Pilot Regions (PRs) possessed some level of information on most topics, yet significant gaps persisted. Citizen involvement and social cohesion data were available in only three PRs, while innovation support data existed in just four. Similarly, institutional governance information was accessible in only six PRs. Despite generally good data accessibility, some datasets existed but were not readily available to PRs. Furthermore, the level of data granularity varied: most regions had information at the LAU level, but topics such as gender imbalances, urban-rural migration, and governance lacked detailed data below NUTS3 level.

A major challenge in the assessment was the **lack of standardization across Living Labs**, which made interregional comparisons difficult and complicated the process of defining Functional Rural Areas (FRAs) for WP1. Nonetheless, the Living Lab experiments relied heavily on local-scale data, reducing the need for external datasets.

→ From a sectorial perspective, **demographic data** was widely available. Migration data, particularly on external migration, was accessible, whereas urban-rural migration figures were mostly aggregated at broader scales. Information on social inclusion and cohesion was unevenly distributed, with very few datasets available at the LAU level, mainly related to education. Housing data was relatively accessible at the local level, but information on





healthcare and education remained limited. Services of General Interest (SGI) data, however, was available through sources like the Rural Observatory and OpenStreetMap (OSM).

- Regarding **local economic development**, PRs mainly relied on OSM and the Rural Observatory, which provided tourism-related data, such as accommodation availability at the LAU level. While employment data per sector was available, other (macro)economic indicators were mostly aggregated at higher spatial levels. Data on innovation support varied significantly across regions; Austria utilized STATCube, North Karelia had some NUTS3-level datasets, and Monmouthshire participated in an innovation data project.
- **Citizen involvement and governance data** also showed regional disparities. Austria had NUTS2-level data from the Voluntary Work survey (2022), while Poland maintained NGO-related data at the same level. The OECD Trust Survey was one of the few available sources for governance insights, and electoral participation was suggested as a potential proxy indicator.
- **Environmental transition** was another critical aspect of the assessment. The most relevant topics identified included sustainable mobility, climate change preparedness, landscape and cultural heritage conservation, and food security in the context of land use conflicts between agriculture and energy production. In contrast, issues such as soil imperviousness, soil erosion, and pollution were considered less significant. Data granularity varied significantly; while landscape and cultural heritage conservation had detailed LAU-level data, information on sustainable mobility, energy production, and biodiversity was largely unavailable.
- For the **digital transition**, the primary focus was on digital infrastructure, whereas digital skills, business digitization, and public service digitization were of secondary importance. Most PRs had access to digital infrastructure data, but datasets on business transformation and digital skills were limited.
- Several challenges were identified in **data collection and use**, including limited expertise in data interpretation and GIS analysis, difficulties in accessing private and public datasets, and a lack of data-sharing initiatives, with only 9 PRs actively sharing their information. Despite these obstacles, many PRs explored innovative data collection approaches. Nine were familiar with web scraping, with seven considering its application, while ten explored participatory GIS (PPGIS). Satellite imagery was recognized as a valuable resource by ten PRs, and eight saw it as particularly relevant to their needs. Some regions also proposed unique initiatives, such as Slovenia's interest in using food waste tracking apps like TooGoodToGo and PriHrani, and Gloucestershire's exploration of AI-powered satellite imagery analysis.
- When it came to **data use in policymaking**, 11 PRs reported using data for policy design and evaluation, yet only six actively monitored policy effectiveness, and just three integrated scientific research data into their processes. In terms of GIS capabilities, 11 PRs demonstrated expertise in data collection and analysis, with eight maintaining georeferenced databases and ten using open-source GIS platforms. However, three PRs lacked internal GIS systems and had to rely on external partners.

In conclusion, the initial assessment showed both strengths and weaknesses in data availability across Living Labs. While inconsistencies and accessibility issues persisted, the Living Lab framework provided a localized approach to overcoming these barriers. By leveraging data experiments, collaboration, and innovative methodologies, Living Labs aimed to enhance data-driven decision-making to support rural transitions.





2.3. Comparative analysis of data experiments, sources and methods

The comparative analysis presented in this section is based on five core dimensions identified across the Second Living Lab reports: experiment objectives, data sources, methods, data innovation, and data issues.

Taken together, these five dimensions provide a comparative framework to assess the maturity, creativity, and practical constraints of rural data experimentation across different territories.

- By reviewing the **objectives of the experiments**, we gain insight into the different thematic focuses and expected outcomes, from supporting foresight activities to informing policy design or stakeholder engagement.
- The section on **data sources** explores the types and origins of data used, distinguishing between official statistics, spatial data, local knowledge, and experimental datasets.
- The **methods** applied across Living Labs vary significantly, ranging from descriptive analyses and participatory workshops to more advanced modelling and scenario techniques. This variety reflects not only the diversity of local capacities, and the flexibility required to adapt to territorial needs, but also the wide range of transitions the Living Labs are addressing, as well as the specific data gaps they identify as critical to fill.
- The category of **data innovation** captures how new approaches, whether technical, methodological, or institutional, have been tested to improve data use and accessibility.
- Finally, the section on **data issues** highlights common barriers, such as fragmentation, lack of granularity, or difficulties in data interoperability.





Table 1. Comparative overview of experiment objectives, data sources, methodologies, innovations, and challenges across the different Living Labs.

Living Lab	Experiment objectives	Data sources	Methods	Data Innovation	Data issues
Galicia	Produce a Decision Support System (DSS) for designating new model settlements, identify additional sources of land ownership information, and understand landowners' participation motivations.	Public data repositories (e.g., Spanish Cadastre, INE, SIOSE, Galician Geographic Information System), interviews with stakeholders, and site visits to model settlements.	Combination of qualitative and quantitative data; multi-criteria evaluation system integrating spatial and non-spatial data; interviews with stakeholders; Decision Support System (DSS) development.	First-time integration of cadastral, biophysical, and social data for policy implementation; decision-making based on cost-effectiveness analysis; introduction of spatial DSS for prioritization of model settlements.	Inconsistencies across sources; outdated land use data (last update in 2017); inaccurate ownership details in the cadastre; disparities in population data across different sources.
Garfagnana - Montagnappennino	Exploring forest functions and needs of operators; Integrating diverse data sources; Mapping Forest characteristics.	Management plans, stakeholder surveys, public funding records; Regional and local databases, web scraping; Geospatial mapping, carbon credit assessments.	Participatory governance, workshops; Data integration from multiple sources; Spatial and statistical analysis.	Innovative data collection and analysis methods. Integration of diverse sources of information, such as stakeholder surveys, focus groups, and mapping techniques.	The data related to the addressed topic are often outdated and fragmented across different sources and institutions.
Gloucestershire	Develop a smart dashboard for data analysis and visualization to support community development and policymaking.	Internal datasets from service organizations, publicly available local and national statistics.	Qualitative interviews, stakeholder engagement, prototyping, AI-driven text generation, and statistical analysis methods (bootstrap analysis, T-tests).	User-friendly dashboard with AI integration for automated reporting, heatmaps for service coverage analysis, and real-time data processing.	Data quality and standardization, varying digital literacy among users, dependency on geographical data for cross-referencing.
Mazowieckie voivodeship - Szydłowiecki powiat	Explore the potential of local natural resources (e.g., chocolate flint) in boosting entrepreneurship and	Primary: Surveys with residents and NGOs, on-site visits, in-depth interviews with entrepreneurs. Secondary: Web scraping of business registries.	Quantitative and qualitative surveys, web scraping, direct observation, structured and semi-structured interviews.	Co-creation process involving entrepreneurs and residents to refine solutions; practical testing of new business ideas leveraging local resources.	Challenges in engaging entrepreneurs, lack of completion of planned activities (e.g., jewellery production from chocolate flint), and variations in local government support.





Living Lab	Experiment objectives	Data sources	Methods	Data Innovation	Data issues
	economic transition in the Radomski subregion.				
Monmouthshire	Understand demographic change and improve balance by attracting/retaining younger people.	<ul style="list-style-type: none"> Office for National Statistics (ONS) Welsh Indices of Multiple Deprivation (WIMD) Ordnance Survey OpenStreetMap Maptionnaire survey Focus groups and interviews Community engagement materials. 	<ul style="list-style-type: none"> Monmouthshire LSOA's ranked in Excel Map files added to comparative dashboard LSOA shapefiles extracted using QGIS Statistical analysis of quantitative questions and thematic analysis of qualitative questions Thematic analysis. 	First-time use of Maptionnaire in a rural context.	WIMD data update delay and LSOA boundary discrepancies affect consistency. Low survey participation limits representativeness of findings.
Nockregion-Oberkärnten	Enhance the visibility of Small Rural Businesses (SRBs), strengthen their role in regional decision-making, and identify key areas for their future development.	<ul style="list-style-type: none"> Spatial data (Google Maps, OpenStreetMaps, IACS, Chamber of Economics, State of Carinthia, local knowledge and municipal lists) Interviews Statistical Data (Registerzählung, Abgestimmte Erwerbsstatistik, Unternehmensdemographie) Survey data (Small Rural Businesses). 	Data mapping, web scraping, stakeholder engagement workshops, and survey distribution.	Innovation is observed in the complex integration of data from reliable, complete, and official spatial sources (IACS, State of Carinthia), collaborative data (OSM, Google Maps), partially public data (Chamber of Economics), and regional expertise (municipal directories and local knowledge).	Lack of real-time data, as the business landscape may have already changed since data collection. Limitation in observing only small rural businesses, requiring an expansion of the analysis to include all businesses regardless of size.
North Karelia	Develop a tool for municipalities to gather data on immigrants and improve employer	Immigrant well-being questionnaire, company interviews, municipal immigration-related databases.	Expert interviews, municipal immigration programs, qualitative and quantitative surveys, business interviews.	Introduction of new data sources, in North Karelia, to improve municipal policies and business integration practices.	Lack of age information (useful for verifying demographics) in interviews with immigrants due to concerns about reducing participation.





Living Lab	Experiment objectives	Data sources	Methods	Data Innovation	Data issues
	awareness of integration processes.				
Osrednjeslovenska regija	Reducing food waste and fostering social inclusion through sustainable food redistribution systems.	Quantitative data on food surpluses from Etri, Likert-type questionnaire.	Data processing using an Excel framework developed as an intermediate phase to transform raw data into working coefficients useful for modelling purposes. Use of an equation that defines a standard meal unit based on caloric intake (SUM-s).	The data experiment's innovation centres on its integrated approach to data sources, collection, and analysis: <ul style="list-style-type: none"> Combining quantitative and qualitative data Social impact metrics Use of localized data Prototype model for policy use 	Limitations regarding what can be tested and modelled with the available data due to data gaps. Difficulty in finding a true rural equivalent for measuring social variables in the context of food distribution.
Parma and Piacenza	Analyse climate change impact on water resources and management; develop integrated monitoring system; improve local water management.	<ul style="list-style-type: none"> SIGRIAN ARPAE 3B Meteo Po River Basin District Authority ANBI Land Reclamation Consortium of Piacenza Italian National Institute of Statistics Land Reclamation Consortia of Parma, Piacenza, Ferrara and CER 	<ul style="list-style-type: none"> Creation of a dataset about water management, surfaces, irrigation volumes, withdrawal source, typology of cultivation, effects of climate change on rainfalls and agricultural cultivations of the LRC irrigation areas. Mapping 	Enhancement of the information system on water management by combining different sources and the understanding of governance peculiarities and specific investment needs of the different water districts.	Data availability, gaps, and comparability issues due to fragmented information across multiple databases, making integration and harmonisation challenging.
Rhein-Hunsrück	Understand challenges faced by employers in filling apprenticeship positions, investigate expectations of young people, identify factors	<ul style="list-style-type: none"> Surveys with young people (290 completed) Employer survey Wildwuchs database (partially) 	Surveys targeting youth and employers, analysis of demographic and labour market data, and preliminary assessment of a	The main innovative aspect is represented by the survey conducted on different groups of young people, combined with existing secondary data.	Young people living outside the district were not included in the survey.





Living Lab	Experiment objectives	Data sources	Methods	Data Innovation	Data issues
	influencing choices, assess measures to support onboarding, and establish sustained information exchange.		regional apprenticeship offer database.	Targeted sampling and distribution of the questionnaire through various channels and multipliers to avoid attracting mainly students with higher education levels and risking an incomplete representation of the experiences and perspectives of different youth groups.	
Sant Miquel de Balenyà	Identify Quality of Life (QoL) disparities across neighbourhoods, develop a localized QoL index, and create a collaborative tool for stakeholders.	<ul style="list-style-type: none"> Repositories and open Data Platforms Smartphone apps (Locus GIS, Kobo toolbox) Maptionnaire. 	<ul style="list-style-type: none"> Web scraping Fieldwork Participatory mapping / paper surveys questionnaires Photo elicitation. 	<ul style="list-style-type: none"> QoL index worked on internally in the Living Lab between the partner and the coordinator. Use of the Maptionnaire application as a tool for collecting data from citizens through the geolocation. 	Challenges related to the survey (not all residents could access the platform, and many who began the survey did not complete it due to its length) and the identification and weighting of QoL indicators, which led to data gaps.
Zaječar District	The objective of the policy experiment is to understand the functioning of the local food supply chain in the tourism sector, to identify the main actors involved, in which sectors (or product groups) they operate and what challenges or obstacles they face.	<ul style="list-style-type: none"> Data came from desk research, web scraping, official statistics, municipal services and tourism organisations. Primary data was collected via Maptionnaire and interviews with key stakeholders. 	A mixed-method approach was used, combining surveys with snowball sampling and social network analysis, along with qualitative interviews.	The study introduced an innovative approach combining web scraping, geospatial mapping, and social network analysis (SNA) to reveal hidden links and optimize relationships in short food supply chains.	While the methodology proved robust, a key limitation was the complexity of the survey tool for some respondents, leading to the exclusion of certain actors like green market vendors.





Living Lab	Experiment objectives	Data sources	Methods	Data Innovation	Data issues
Troyan-Apriltsi-Ugarchin	<ul style="list-style-type: none"> Primary objective: to understand the roots of informality in the agri-food sector and the barriers actors face in complying with policies. Secondary goal: to explore cooperation within rural agri-food networks and their potential to drive local development. Further objectives: to examine cultural and socio-technical factors influencing collaboration, aiming to support visibility, innovation, and new local food branding. 	Data were collected through in-depth interviews, GIS-based desk research, participatory experiments with restaurants, and direct observation at food festivals and markets.	The study combined self-reported, unobtrusive, participatory, and observational methods to map agri-food networks, track local food flows, and engage actors in real-time collaborative data collection.	The experiment introduced an innovative triangulation of GIS data, interviews, observations, and real-time collaboration, creating a new framework for analysing local food systems and supporting community-based decision-making.	A key limitation is the inability to quantify the informal food sector, but qualitative data proved more effective in understanding its dynamics and identifying supportive policy approaches.
Świętokrzyskie	Diagnose and develop rural tourism strategies to counteract demographic decline.	<ul style="list-style-type: none"> Social research (surveys among agritourism farm owners and tourists) Websites of tourist entities Google Maps inventory. 	Data collection to inventory and locate rural tourist facilities in the Świętokrzyskie region. An information sheet was created for 160 agritourism farms, with partial data	The research combined established and innovative data collection methods, and the research was conducted at various spatial scales and locations covering the entire region. Innovative forms	Lack of comprehensive statistical data on rural tourism, reluctance of stakeholders to participate in surveys.





Living Lab	Experiment objectives	Data sources	Methods	Data Innovation	Data issues
			<p>verification through telephone contact.</p>	<p>of data acquisition include the use of the Google Maps application and a wide range of websites of agritourism farms. Another innovative method of data acquisition were study visits to model agritourism farms and presentations prepared by owners of model tourist facilities.</p>	



2.4. Identified challenges related to data collection

The analysis of data-related challenges reported by the different Living Labs shows several recurring issues that affect the reliability, completeness, and usability of the information collected for rural development strategies.

The most common limitations revolve around outdated or incomplete data, difficulties in integrating fragmented datasets from multiple sources, low participation in surveys affecting data representativeness, and challenges in capturing real-time changes in local economies and social dynamics.

Next, each of these topics are discussed:

- **Outdated and fragmented nature of data.** This is highlighted in several cases, such as the Galicia Living Lab, where land use data had not been updated since 2017, and ownership records contained inaccuracies. Similarly, multiple Living Labs reported difficulties with integrating data due to inconsistencies and fragmentation—making standardization and harmonization highly challenging. For example, the Slovenian and Finnish cases both noted significant data availability and comparability issues due to fragmented datasets and gaps, complicating cross-referencing and modelling work.
- **Lack of real-time or up-to-date data,** particularly in contexts where the local business landscape or social structures and processes evolve rapidly. The Austrian Living Lab experienced this challenge, finding that by the time data on small rural businesses was collected, the situation on the ground had already changed. This reflects a broader problem in rural data collection: static datasets often fail to capture dynamic changes in local economies.
- **Survey-based data collection** also faced multiple limitations, particularly regarding **participation rates and representativeness.** In the Welsh Living Lab, low survey participation combined with boundary discrepancies undermined the consistency of findings. Similarly, in Sant Miquel de Balenyà (Spain), many residents did not complete the quality-of-life survey due to its length, leading to data gaps and difficulties in properly weighting indicators. In Rhein-Hunsrück (Germany), the youth survey failed to include young people living outside the district, limiting the representativeness of the results.
- Specific challenges also emerged around the **quality and completeness of social and demographic data.** For example, in North Karelia (Finland), collecting age information from immigrants proved sensitive, as it risked reducing participation. Additionally, measuring social variables for food distribution posed difficulties in Slovenia, due to a lack of rural-specific metrics and data gaps.
- Less frequently reported but notable issues include **digital literacy barriers,** particularly where users struggled to access or complete online surveys, and limited market flow data, which affected the ability to track supply chains and economic exchanges—highlighted in the Serbian case. Similarly, weak cooperation among agri-food actors and informal economic practices complicated efforts to trace and model food systems.

- Finally, **stakeholder engagement and participation** emerged as challenges in specific contexts. The Świętokrzyskie Living Lab (Poland) reported reluctance from tourism stakeholders to participate in surveys, while the Mazowieckie Living Lab struggled with entrepreneurial engagement and completing planned activities.

2.5. Reflections on data sources, methods and tools

The experience gained across the Living Labs triggered a set of cross-cutting reflections regarding the use of data sources, methodologies, and tools adopted to address the transitional challenges of rural areas. The experimental activities conducted in the various pilot regions made it possible to identify recurrent issues while also showcasing innovative approaches and solutions, offering valuable insights for shaping future data-driven rural development strategies.

- A first key takeaway concerns **difficulties in accessing relevant and up-to-date data at the local scale**, and also ways of solving those difficulties. While most Living Labs encountered issues such as data fragmentation, limited granularity, or the difficulty of obtaining disaggregated datasets for local-level analysis, these challenges have also fostered creative responses and methodological innovation. For instance, in regions like Garfagnana or Parma, Piacenza, and Ferrara, forestry or water governance data were spread across various public and private stakeholders, requiring coordination efforts to build an integrated understanding of territorial dynamics. Similarly, the Galicia Living Lab worked with outdated and inconsistent cadastral data, which limited wildfire risk planning, but prompted in response the development of new data integration strategies. Several Living Labs identified gaps in data coverage for specific economic sectors or population groups of relevance to their experiments—such as rural SMEs in Nockregion-Oberkärnten, unemployed youth in Rhein-Hunsrück, or informal agri-food producers in Troyan-Apriltsi-Ugarchin. This brought attention to the need for more inclusive data systems. In contrast, Świętokrzyskie’s experience illustrates a different type of challenge: an abundance of national statistics that do not always translate into actionable insights at the local level.
- A second crucial dimension concerns the **integration of diverse data sources**. Several Living Lab experiences demonstrated that merging heterogeneous datasets—quantitative, qualitative, spatial, and non-spatial—provides significant added value for understanding complex territorial dynamics. In Galicia, for instance, the combination of environmental and social datasets enabled the creation of a Decision Support System (DSS) for wildfire risk management and agricultural planning. Similarly, the Osona Living Lab effectively integrated geo-referenced indicators such as air quality measurements, accessibility levels, and land use changes with participatory mapping to develop an innovative Quality of Life Index. The Index allows to capture and visualize socio-territorial inequalities, informing public policy decisions and prioritization of local interventions aimed at enhancing territorial cohesion and well-being.
- The experimentation phase further emphasized that **adopting innovative tools and methods**—such as GIS, Artificial Intelligence, interactive dashboards, and web scraping—can significantly expand analytical and decision-making capacities. However, these approaches require adequate technical skills and dedicated resources. Experiences from Zaječar and Nockregion demonstrated the potential of techniques like web scraping.
- Another fundamental lesson concerns the **role of participation and inclusiveness in data collection and interpretation processes**. Several Living Labs activated participatory approaches involving citizens, businesses, and local authorities, demonstrating that territorial knowledge is an essential asset for bridging data gaps and enhancing the quality and

legitimacy of analyses. Examples include participatory mapping exercises and local workshops carried out in Osona, Monmouthshire, and Zaječar.

- At the same time, the Living Labs reinforced the understanding that the capacity to use and govern data constitutes a form of **empowerment for local actors**. Strengthening digital and analytical skills among local authorities and rural communities proved essential to ensure that the collected data could effectively inform planning processes and public policies.
- However, several common challenges emerged across contexts. The complexity of data collection and cleaning, the difficulty of ensuring data is regularly updated, and challenges related to personal data protection and privacy were recurring issues. These challenges highlight the need to design more robust and sustainable rural data governance models. While the integration of diverse sources and methodologies stands out as one of the most significant innovations, it also required far greater time and resources than initially anticipated.
- Finally, a cross-cutting reflection underscores the urgent need to **overcome the digital divide and to make data collection and analysis technologies accessible** even in the most remote rural contexts. The potential offered by advanced tools such as GIS, dashboards, and data visualization platforms is vast but risks remaining untapped without parallel investments in capacity building, digital infrastructure, and technical support.

2.6. RUSTIK best practices for overcoming challenges

In this section, we present the comparative overview of the innovative methods used in the Living Labs. Most of the innovations focus on the integration of diverse data sources and their presentation in accessible formats such as maps or dashboards.

- A recurring innovative approach observed across the Living Labs is the **combination of diverse data sources** to enhance the understanding of local contexts and support more informed, evidence-based decision-making processes in rural areas. This integration effort often involves official datasets, collaborative data, and local knowledge. This method allows for cross-verification of information, the filling in of data gaps, and the enrichment of analysis with qualitative insights that purely statistical data would not provide.
 - For instance, the [Galicia Living Lab \(Spain\)](#) applies this approach by integrating cadastral, biophysical, and social data to support land use planning processes and risk reduction strategies, particularly for wildfire prevention and the revitalization of rural economies through new farming activities.
 - Similarly, the [Nockregion-Oberkärnten Living Lab in Austria](#) demonstrates an advanced form of triangulation, where official data sources—such as the Integrated Administration and Control System (IACS) and information from the State of Carinthia—are combined with collaborative datasets like OpenStreetMap and Google Maps. Additionally, local territorial knowledge—gathered from municipal directories and the expertise of local stakeholders—is included to create a more comprehensive and accurate spatial representation of small rural businesses (SRBs) in the region.
 - [Garfagnana - Montagnappennino](#). This Living Lab worked on integrating diverse sources of information, such as stakeholder surveys, focus groups, and mapping techniques.

- **Use of digital tools for mapping and spatial analysis.** An important technological advancement observed across several Living Labs is the use of digital platforms and tools for mapping and spatial data analysis, which significantly enhances both the accessibility, and the quality of information used in territorial planning and community engagement. In particular, the Maptionnaire platform emerges as a key example of this innovation, being applied in two distinct cases with different purposes and impacts.
 - On one hand, it was used for the first time in a rural context within the [Monmouthshire Living Lab](#), marking an important step towards adapting digital citizen engagement tools traditionally used in urban settings to the specific needs and challenges of rural areas.
 - On the other hand, Maptionnaire was employed as a citizen engagement tool in the [Sant Miquel de Balenyà](#) Living Lab, enabling the collection of georeferenced data directly from the population. This participatory approach allowed local residents to actively contribute their knowledge and perspectives, generating highly localized datasets that reflect the community's lived experience and priorities. Beyond enhancing data granularity for rural planning, such experiential and observational knowledge is particularly valuable for addressing complex transition challenges, where official datasets may fall short. Moreover, this kind of inclusive data collection

has the potential to democratize policy and planning processes—an increasingly important consideration in light of growing discontent and perceived marginalisation among populations in remote, rural or declining areas.

- Moreover, the introduction of **interactive dashboards enhanced with Artificial Intelligence (AI)** capabilities represents a significant technological leap forward. These systems enable automated report generation, real-time data processing, and the creation of dynamic visual outputs such as heatmaps, which can immediately illustrate service coverage or identify gaps across a territory.
 - A notable example of this is the Gloucestershire Living Lab, where the AI-powered dashboard allows local decision-makers to perform instant analyses of service provision levels across rural communities. This tool not only supports data-driven policymaking but also facilitates the continuous monitoring of territorial dynamics, making it easier to adapt strategies and interventions over time based on real-time evidence.

- **Co-creation processes and engagement of local actors.** One of the most valuable innovative approaches identified across several Living Labs is the active involvement of local stakeholders in co-creation processes aimed at developing context-specific solutions and strengthening community ownership of the initiatives. These participatory methods foster collaboration between diverse groups—ranging from entrepreneurs and residents to businesses and local authorities—ensuring that the strategies and tools developed truly reflect local needs, resources, and priorities.
 - For example, in the Mazowieckie Living Lab (Poland), entrepreneurs and residents were directly involved in the co-development of new business ideas rooted in the sustainable use of local natural resources. This participatory process not only encouraged creative thinking but also helped identify untapped economic opportunities that align with the region’s environmental characteristics and socio-economic context.
 - Similarly, in the Rhein-Hunsrück Living Lab (Germany), a series of focus groups were organized with young people and employers to explore challenges and barriers in the local apprenticeship market. This dialogue allowed both sides to share their perspectives, contributing to a deeper understanding of the mismatch between the supply of skilled labour and the demand from local businesses, and informing targeted interventions to improve vocational training and job opportunities for rural youth.
 - In Serbia’s Zaječar District, the Living Lab facilitated a participatory mapping process of the local agri-food supply chain, actively engaging restaurateurs, small and medium-sized enterprises (SMEs), and farmers. Through this collaborative effort, stakeholders were able to visualize the existing local networks, identify gaps and potential synergies, and lay the groundwork for strengthening local production-consumption loops.

→ Notable cases of innovation.

- The Osrednjeslovenska Living Lab (Slovenia) stands out for its integrated approach combining quantitative and qualitative data, social impact metrics, and localized information. This methodology led to the creation of a prototype model designed for use in public policy, offering a more comprehensive and context-sensitive analytical tool. A key strength of this case is the particular attention given to ensuring representativeness in youth surveys. To overcome potential biases—such as over-representation of highly educated respondents—targeted sampling techniques and diverse distribution channels were used. This ensured the inclusion of a wide range of perspectives and socio-economic backgrounds, improving the reliability and relevance of the results for policymaking.
- Study visits to model agritourism farms and multi-source data collection, Świętokrzyskie Living Lab (Poland). Study visits to model agritourism farms have been organized as a key method for collecting data and facilitating knowledge transfer. These visits allowed participants to observe successful business models firsthand, understand operational practices, and directly engage with farm owners, gaining valuable insights into the challenges and opportunities of agritourism development. In parallel, the Living Lab collected data from a wide range of online sources, including websites of agritourism farms and related platforms, to complement the field observations. Additionally, presentations were prepared and delivered directly by the owners of model tourist facilities, providing real-life examples of best practices, business strategies, and innovative solutions adopted in the sector.

2.7. Lessons learned: data availability and capacities gaps, and strategies to address them

The following table summarizes the main gaps and limitations encountered by the living labs during the development of various experiments, along with the strategies they implemented to address these challenges. The identified gaps and limitations are categorized into seven distinct topics: data availability, data collection, data granularity, digital transition, environmental data, socioeconomic data, and GIS capabilities.

Table 2. Mapping of data issues, strategic responses, and implementation cases by topic.

Topic	Gaps/Limitations	Strategies	Examples
Data Availability	<ul style="list-style-type: none"> Data availability is limited due to fragmented information across various sources and institutions, making it difficult to integrate and harmonize the data. The lack of real-time data poses an obstacle, as changes in the business landscape could render the collected data obsolete. There are gaps in comprehensive statistical data, such as in rural tourism, due to reluctance from stakeholders to participate in surveys. Market flow data is often insufficient, making it difficult to monitor and analyse economic changes. Demographic data, such as age information, is often missing or incomplete, limiting the accuracy of analyses, particularly for interviews with immigrants. 	<ul style="list-style-type: none"> Integration of heterogeneous data through GIS systems and data viewers. Use of available data with gradual updates over time Direct involvement of actors through qualitative surveys and focus groups. Real-world local tracking experiments to gather market data. Targeted surveys and collaboration with local stakeholders to collect demographic data. 	<ul style="list-style-type: none"> Slovenia integrated food and social data into a single GIS model to reduce waste. Slovenia abandoned real-time data and used existing sources with updates. North Karelia conducted well-being surveys for immigrants and youth. Troyan tracked local sales through restaurants and weekly data collection. North Karelia built demographic profiles by integrating surveys and focus groups.
Data Collection	<ul style="list-style-type: none"> Data related to specific topics is often fragmented and outdated, creating difficulties in applying them to current issues. There are challenges in engaging entrepreneurs in planned activities and completing projects due to insufficient local government support and low participation. 	<ul style="list-style-type: none"> Collection and digitization of secondary data from public registers and direct observations. Building networks among entrepreneurs and promoting through local branding. Collaboration with research institutions to integrate academic data. 	<ul style="list-style-type: none"> Troyan transformed registry data into GIS maps and gathered observations from markets. Mazowieckie promoted the 'chocolate flint' brand to encourage entrepreneurial participation.
Data Granularity	<ul style="list-style-type: none"> Difficulties in finding a "rural equivalent" to measure social variables prevent the application 	<ul style="list-style-type: none"> Adaptation of qualitative methods 	<ul style="list-style-type: none"> Slovenia adapted urban indicators and used

Topic	Gaps/Limitations	Strategies	Examples
	<p>of standardized methods for assessing issues like food distribution.</p> <ul style="list-style-type: none"> Data gaps limit the ability to test and model variables and behaviours effectively, reducing the precision of the analyses. This challenge is directly addressed by the concept of Functional Rural Areas (FRAs), as proposed in the delimitation methodology currently endorsed by the European Commission and Eurostat (Dijkstra & Jacobs-Crisioni 2023, 2024). FRAs aim to improve the comparability and statistical representativeness of rural spatial units by moving beyond administratively-defined boundaries (such as LAUs, which are often too heterogeneous) toward areas defined by socio-economic functionality and spatial interactions—akin to the approach used for Functional Urban Areas (FUAs). 	<p>and use of participatory models.</p> <ul style="list-style-type: none"> Local scale modelling using triangulated qualitative and quantitative data. 	<p>focus groups with food NGOs.</p> <ul style="list-style-type: none"> Garfagnana modelled scenarios with forest and territorial qualitative data.
Digital Transition	<p>Data availability is primarily focused on digital infrastructure, with limited coverage on digital skills, public services, digital business transformation, innovation, and the granular aspects of digital transition, while the adoption of digital innovation remains limited across public resources.</p>	<ul style="list-style-type: none"> Digital dashboards, digital literacy workshops, and use of innovative indicators. 	<ul style="list-style-type: none"> Gloucestershire developed a dashboard for rural services and organized digital inclusion events. Garfagnana: Digitization of ecosystem data to support governance.
Environmental Data	<p>Data on sustainable mobility, biodiversity, climate change, and forest management are limited, with a focus primarily on macro scales and basic area delimitation, lacking qualitative insights.</p>	<ul style="list-style-type: none"> Integrated use of spatial and cadastral data, with involvement of local actors. 	<ul style="list-style-type: none"> Galicia integrated land use, biophysical, and cadastral data to assess wildfire risk.
Socioeconomic Data	<p>While demographic grid datasets, such as 1 km² census-based grids and platforms like WorldPop, do provide spatialized data on basic age and gender structures, detailed socioeconomic data below the NUTS3 level remains scarce across most public resources. Key aspects such as gender imbalance in socio-economic roles, urban-rural migration flows,</p>	<ul style="list-style-type: none"> Local surveys to improve data granularity. Standardization of socioeconomic data collection methodologies across PRs. 	<ul style="list-style-type: none"> Monmouthshire: Study of migration trends and strategies to retain young residents. Rhein-Hunsrück: Data collection to reduce youth exclusion in rural areas.

Topic	Gaps/Limitations	Strategies	Examples
	institutional governance, and broader socio-economic transitions are still poorly represented and often lack harmonized datasets.	<ul style="list-style-type: none"> Creation of open-source GIS platforms and training of local actors. 	
GIS Capabilities	Several public resources lack in-house GIS expertise and systems, with some relying on open-source GIS, and only a few having dedicated GIS specialists or developed online map viewers.	<ul style="list-style-type: none"> Participatory construction of socio-economic indicators through mapping and local workshops. Creation of open-source GIS platforms and training of local actors. 	<ul style="list-style-type: none"> Troyan-Apriltsi-Ugarchin: GIS platform for monitoring food production. Parma-Piacenza-Ferrara: Use of GIS to optimize water resource management. Monmouthshire mapped inequalities using QoL indicators and geo-referenced qualitative data.

Source: own elaboration

3. RUSTIK Database and RUSTIK Rural Functions

3.1. Aim

The project identified and described five key functions that rural areas can provide in support of broader territorial, environmental, and socio-economic systems. These functions included:

- 1) **Provision of ecological services** (water quality and quantity, energy, biodiversity, landscape soil conservation, leisure, carbon sequestration, etc.), especially for the benefit of non-rural populations.
- 2) **Specific innovative infrastructures and services both for rural populations** (schools, local transport, healthcare services, broadband networks, irrigation and reclamation networks, etc.) **and for non-rural populations** (tourism and recreation facilities, etc.).
- 3) **Provision of high quality and accessible land-based products**, from agriculture, forestry, energy and other land-based activities.
- 4) **Distributed and diversified production systems**, incorporating small and medium enterprises, new forms of industrial activities (e.g., industry 4.0), and entrepreneurial capacities which can be exploited for the creation of new economic activities and rural-urban networks.
- 5) **Social capital, cultural assets** (including cultural heritage) **and cooperative institutions**, which contribute to strengthening the four functions above and offer relevant potential for resilience and development.

Given the strategic relevance of these functions within rural contexts, the comparative overview aims to assess the extent to which existing indicators, both at the European and local levels, can capture and represent the five rural functions defined within the framework of the project. The goal is to understand which functions are most represented, which are less covered, and how different local contexts shape the approach to measuring and supporting rural functions.

It is important to note that the data analysed are not exhaustive, as they include only those indicators available at the time of the comparative overview.

3.2. Methodology

The analysis was structured in three main phases: mapping European-level indicators, testing the approach with Living Labs indicators, and identifying and addressing data gaps. These phases are detailed below.

1. Mapping European-level indicators

In the initial phase, a mapping and classification of European-level indicators previously selected within the RUSTIK project was carried out. The aim was to evaluate their relevance in relation to the five rural function concepts forming the theoretical foundation of the study.

Each indicator was reviewed individually, considering its informational content and its conceptual alignment with one or more of the rural functions. Based on this analysis, indicators were assigned to the function they best represented. Indicators have been aligned to more than one concept in case they have a strong relation with several functions.

2. Testing the approach with Living Labs

In the second phase, the methodology from Phase 1 was applied to the Living Labs to assess the relevance and applicability of the rural function framework at the local scale. Indicators from each Living Lab were reviewed and classified using the same analytical structure as for the European-level data and assigned to one or more rural functions based on their thematic focus and intended use.

In parallel, a comparative analysis was conducted between local and European indicators to identify thematic correspondences, conceptual overlaps, and differences in data granularity. This step was relevant to evaluate which level of analysis, European or local, offered greater capacity to meaningfully describe and measure the five rural functions.

3. Identifying and addressing data gaps

The third phase focused on a critical assessment of the findings from Phase 2, particularly regarding the effectiveness of both European and local indicators in representing the rural functions. This evaluation highlighted not only the strengths of the current data infrastructure but also its limitations and inconsistencies.

A key outcome of this phase was the identification of informational gaps—specific functions or thematic areas where the available indicators were either insufficient or entirely lacking, thereby limiting the capacity for comprehensive assessment.

3.3. Results

European Level

The classification exercise of the European-level indicators provided an initial quantitative overview of the functional coverage offered by the existing information system. The indicators were distributed across the five rural functions as follows:

- 33 indicators related to the provision of ecosystem services,
- 21 to innovative infrastructures and services,
- 16 to the provision of high-quality and accessible land-based products,
- 15 to distributed and diversified production systems,
- 16 to social capital, cultural assets and cooperative institutions.

This distribution shows a relatively good level of representation across all categories at the European level. However, a higher concentration of indicators was observed under the function related to ecosystem services, while others, such as production systems and land-based products, appear to be less represented.

Local Level

The classification of the local-level indicators across the five rural functions provides a nuanced overview of how territorial dynamics are captured through existing data sources. The indicators were distributed among the functions as follows:

- 18 indicators related to the provision of ecosystem services,
- 21 to innovative infrastructures and services,
- 46 to the provision of high-quality and accessible land-based products,
- 57 to distributed and diversified production systems,
- 168 to social capital, cultural assets and cooperative institutions.

It is important to note that several indicators are multipurpose and contribute to more than one rural function. This overlapping reflects the interconnected nature of rural systems, where, for example, an indicator on agroforestry practices may simultaneously inform ecosystem services and land-based production.

The current distribution reveals a particularly strong emphasis on social capital and cooperative institutions, which gather the highest number of indicators. This may indicate both the availability of local data in this area and the prominence given to social cohesion and governance aspects in rural development agendas.

On the other hand, ecosystem services and innovative infrastructures remain less represented. This suggests the need for enhanced monitoring tools and data systems that can better capture environmental processes and the diffusion of innovation in rural areas.

This uneven distribution of indicators across functions is also partly attributable to the variation in contributions from the different Living Labs. Some LLs submitted a significantly higher number of local-level indicators, while for others, data collection was still ongoing at the time of drafting

this report. As a result, certain LLs are more prominently represented in the following tables, creating a perceived dominance in specific rural functions.

Comparison between European and Local Level

1. Provision of ecosystem services

The analysis of the indicators associated with the rural function “Provision of Ecosystem Services” reveals a broad and multidimensional information landscape.

- The **European indicators** provide a framework for assessing key regulating and provisioning ecosystem services. These include variables related to land use (forest, agricultural, and grassland proportions), vegetation cover (Tree Cover Density, Leaf Area Index, NDVI), biodiversity (presence of Natura 2000 and Emerald protected areas), and environmental risks (drought frequency, forest fire danger, projected changes in precipitation). Additionally, indicators on renewable energy production (solar, wind, hydropower) and air quality (ozone, PM10, PM2.5) offer essential insights into the environmental sustainability and ecological performance of rural territories.
- In parallel, **local indicators** developed through Living Labs enrich the picture by introducing a territorial and experience-based perspective. Indicators such as access to green and recreational spaces, perceived quality of life, walkability, and neighbourhood safety and noise levels help monitor cultural and social ecosystem services, which are often neglected in conventional environmental monitoring. These data are particularly valuable for place-based planning focused on wellbeing, territorial equity, and climate adaptation.

When comparing the two levels, it is evident that European indicators are effective in describing environmental and biophysical processes at broader scales due to their harmonization and comparability. However, local indicators—often developed through social research methods—are indispensable for capturing the everyday value and lived experience of ecosystem services, offering a more granular and context-specific reading of human-environment interactions. The added value of methodological triangulation lies in the possibility of using these locally grounded insights to calibrate and interpret datasets with full territorial coverage. For instance, bottom-up assessments of preferred land use combinations or perceived environmental quality can help refine top-down data models and inform more context-sensitive policy responses.



Table 3. European and LL indicators related to “Provision of ecosystem services” function.

Topic	European Indicators	Living Labs Indicators
Air quality	<ul style="list-style-type: none"> •Air quality of Ozone [$\mu\text{g}^*\text{d}/\text{m}^3$] •Air quality of PM10 [$\mu\text{g}^*\text{d}/\text{m}^3$] •Air quality of PM2.5 [$\mu\text{g}^*\text{d}/\text{m}^3$] 	<ul style="list-style-type: none"> •Air and acoustic pollution, Osona (ES)
Biodiversity	<ul style="list-style-type: none"> •Forest Proportion of Land (%) •Projected change in meteorological forest fire danger •Average meteorological forest fire danger 1981-2010 •Plant Phenology Index 2016-present, daily •Forest Type, 3-yearly •Dominant Leaf Type •Grassland, 3-yearly •Grassland Change 2015-2018 •Vegetation Indices Quality Flag 2016-present •Leaf Area Index 2016-present, daily 	<ul style="list-style-type: none"> •Neighbourhood noisy spaces, Osona (ES)
Landscape soil conservation	<ul style="list-style-type: none"> •Built Proportion of Land (%) •Areas burnt by wildfires •Agricultural Proportion of Land (%) •Riparian Zones Land •Cover/Land Use, 6-yearly •Riparian Zones Land •Cover/Land Use Change 2012-2018, 6-yearly •Normalised Difference •Vegetation Index 2016-present 	<ul style="list-style-type: none"> •Neighbourhoods Climate, Osona (ES), Osona (ES) •Shelters Responses, Osona (ES) •Urban Landscape Quality, Osona (ES)
Energy	<ul style="list-style-type: none"> •Hydropower Production •Solar Production •Onshore Production 	<ul style="list-style-type: none"> •Energy efficiency certifications, Osona (ES)
Water quality and quantity	<ul style="list-style-type: none"> •EU-Hydro River Network •Database 2006-2012 •Water and Wetness status, 3-yearly 	
Leisure		<ul style="list-style-type: none"> •Green public space proximity, Osona (ES) •Green and recreational spaces, Osona (ES) •Neighbourhood Walking Spaces, Osona (ES)
Carbon sequestration	<ul style="list-style-type: none"> •Tree Cover Density, 3-yearly •Small Woody Features, 3-yearly •Natura 2000 Protected Areas •Emerald Protected Areas •Mountain Areas •Projected changes in heavy precipitation •Drought Frequency Change 	<ul style="list-style-type: none"> •Perception of the quality of life, Osona (ES) •Neighbourhood dangerous spaces, Osona (ES) •Quality of life by neighbourhood, Osona (ES) •Quality of life Grid Calculation, Osona (ES) •Neighbourhood Walking Spaces, Osona (ES) •Quality of Life, Osona (ES) •Lack of Space in the Household, Osona (ES)

Source: own elaboration.



2. Innovative infrastructures and services

The indicators classified under the rural function “Innovative Infrastructures & Services” provide a view of how accessibility, service provision, and territorial development are monitored at both European and local levels. This function encompasses key components of rural vitality, such as education, healthcare, commerce, mobility, tourism, digital connectivity, and administrative infrastructure.

- At the **European level**, the indicators are primarily composed of geolocated services of general interest—schools, hospitals, train stations, pharmacies, cinemas, retail shops, banks, and cultural facilities—accompanied by grid-based accessibility measures. These indicators allow for a broad and comparable mapping of basic services and infrastructures, and can support the evaluation of spatial inequalities, remoteness, and service desertification across rural regions. Additionally, the inclusion of high-speed mobile and fixed network coverage introduces a crucial dimension of digital accessibility, which is essential for modernizing rural economies and bridging the urban-rural digital divide.
- Complementing this, the **Living Lab indicators** enrich the dataset with fine-grained, place-based information. These include heatmaps of healthcare, services, and administrative functions (notably in Osona, Spain), as well as data on commercial dynamics (e.g. active vs. empty premises), the presence of rural tourism and hospitality services (in Troyan, Bulgaria and Zajecar District, Serbia), and employment in the tertiary sector (Upper Carinthia, Austria). Moreover, planning tools such as the “model settlement” instrument for territorial prioritisation in Galicia (Spain) reflect efforts to steer investment in services and infrastructures toward targeted rural areas.

Comparing both levels, it becomes clear that European indicators excel in offering uniform, scalable data on service availability and accessibility, particularly in essential domains such as education, health, mobility, and digital infrastructure. However, their aggregated nature limits their ability to reflect qualitative aspects, such as service adequacy, user experience, or socio-economic performance.

In contrast, local indicators are more flexible and capable of addressing the multidimensionality of rural services, offering context-specific insights that are crucial for policy targeting, stakeholder engagement, and place-based planning. They provide deeper granularity, especially in the mapping of service gaps, tourism intensity, and commercial activity trends, thus allowing for a more dynamic and responsive interpretation of territorial needs.



Table 4. European and LL indicators related to “Innovative infrastructures and services” function.

Topic	European Indicators	Living Labs Indicators
Tourism and recreation facilities	<ul style="list-style-type: none"> • Culture Points of Interest • Nature and Forestry. Points of Interest • Restauration. Points of Interest • Sports and Leisure. Points of Interest • Touristic Assets. Points of Interest • Touristic Information. Points of Interest 	<ul style="list-style-type: none"> • Commercial establishments offering local food, Troyan (BG) • Restaurants, Zajecar District (RS) • N of Restaurants, Troyan (BG) • Rural tourist households, Zajecar District (RS) • Enterprises in accommodation in Radomski subregion, Woj. Świętokrzyskie (PL) • Hospitality establishments, Zajecar District (RS) • N of hotels and accommodations per municipality, Troyan (BG) • Hotels, Zajecar District (RS)
Healthcare services	<ul style="list-style-type: none"> • Hospitals. Points of Interest, Grid, and Accessibility • Doctors. Points of Interest, Grid, and Accessibility • Pharmacies. Points of Interest, Grid, and Accessibility • Health. Points of Interest 	<ul style="list-style-type: none"> • Healthcare Point of Interest, Osona (ES) • Healthcare Heatmap, Osona (ES)
Broadband networks	<ul style="list-style-type: none"> • Access to high-speed mobile network • Access to high-speed fixed network 	<ul style="list-style-type: none"> • Average Broadband Speed and Availability by OA11 by year 2016-2022, Gloucestershire
Local transport	<ul style="list-style-type: none"> • Tran Stations. Points of Interest, Grid, and Accessibility 	
Schools	<ul style="list-style-type: none"> • Primary Schools. Points of Interest, Grid, and Accessibility • Secondary Schools. Points of Interest, Grid, and Accessibility 	
Services	<ul style="list-style-type: none"> • Banks. Points of Interest, Grid, and Accessibility • Commercial Activities. Points of Interest • Industry. Points of Interest • General Services. Points of Interest 	<ul style="list-style-type: none"> • Services Point of Interest, Osona (ES) • Services Heatmap, Osona (ES) • Prioritisation of settlements for the implementation of the ‘model Settlement’ instrument, Galicia (ES) • Administrative Point of Interest, Osona (ES) • Administrative Heatmap, Osona (ES)

Source: own elaboration.



3. Provision of high-quality and accessible land-based products

The rural function “Provision of high-quality & accessible land-based products” plays a central role in the sustainability and resilience of rural territories. It encompasses not only the physical and environmental availability of agricultural land, but also the capacity of local systems to generate value, ensure food accessibility, and support diversified and quality-based production models. The set of indicators compiled—spanning both European-level data and highly detailed local insights—offers a multidimensional framework to assess this function.

- At the **European level**, indicators are primarily focused on land use structure and natural resources, including forest, agricultural, and built-up land proportions, vegetation cover types, and coastal land use. These are complemented by data on renewable energy production (solar, onshore, and hydropower), highlighting the multifunctionality of rural landscapes. These indicators are particularly well-suited to evaluating the spatial distribution and environmental potential of productive land, and they provide valuable inputs for large-scale planning and cross-territorial comparisons.
- In contrast, the **Living Lab indicators** offer a granular and context-sensitive view of agricultural activity and local food systems. These local indicators capture structural farm data (e.g., average land plot size, number of livestock, work units), land ownership patterns, and the economic diversification of rural enterprises through secondary and value-added activities such as processing, agritourism, handicrafts, and direct sales. Particularly notable are the indicators that monitor the share of farms selling over 50% of their production, often linked to specific processing or market channels—such as dairy, fruit and vegetable processing, wood, or online platforms. Additionally, the inclusion of value chain indicators—tracking food supply chains (e.g., eggs, meat, fish, flour, honey) and market access (e.g., green markets, direct sales, buyers of local products)—provides a rich understanding of how rural products reach consumers and contribute to local food sovereignty and rural-urban linkages. This level of detail is essential to assess not only production volumes, but also the embeddedness of farms within the local economy and their ability to respond to market demands and sustainability challenges.



Table 5. European and living labs indicators related to “Provision of high-quality and accessible land-based products” function.

Topic	European Indicators	Living Lab Indicators
<p>Energy and other land-based activities</p>	<ul style="list-style-type: none"> • Built Proportion of Land (%) • Solar Production • Onshore Production • Hydropower Production • Coastal Zones Land Cover/Land Use, Europe, 6-yearly • Coastal Zones Land Cover/Land Use Change 2012-2018, Europe, 6-yearly 	<ul style="list-style-type: none"> • Farms selling over 50% of their production and engaged in energy production (number), Zajecar District (RS) • Farms selling over 50% of their production and engaged in public utility services, Zajecar District (RS)
<p>Agriculture</p>	<ul style="list-style-type: none"> • Agricultural Proportion of Land (%) • Urban Atlas Land Cover/Land Use (vector), Europe, 6-yearly • Urban Atlas Land Cover/Land Use Change (vector), Europe, 6-yearly • CLC+Backbone 2018 (raster 10 m), Europe, 3-yearly • Agricultural Area 	<ul style="list-style-type: none"> • Employment rate % of primary sector - agriculture and forestry, Upper Carinthia (AT) • Average size of land plot (ha), Galicia (ES) • N of livestock farms per municipality, Troyan (BG) • N of apiaries per municipality, Troyan (BG) • N of enterprises NACE_rev 2_A (Agriculture), Troyan (BG) • INVEKOS Hofstellen / IACS farmsteads, Upper Carinthia (AT) • Employment rate % of primary sector - agriculture and forestry, Upper Carinthia (AT) • Ratio between landowners and inhabitants at municipal level, Galicia (ES) • Livestock units (LSU) per farm (number) (2023), Zajecar District (RS) • Annual work unit (AWU) per farm (number) (2023), Zajecar District (RS) • Percentage of farms selling over 50% of the value of their production (%), Zajecar District (RS) • Percentage of farms with other gainful activities (OGA) (%), Zajecar District (RS) • Percentage of farms selling over 50% of their production and engaged in other gainful activities (OGA), Zajecar District (RS) • Standard output (SO) of farms selling over 50% of their production (euros), Zajecar District (RS) • Standard output (SO) of farms selling over 50% of their production and engaged in other gainful activities (OGA) (euros), Zajecar District (RS)





- Farms selling over 50% of their production and engaged in meat processing (number), Zajecar District (RS)
- Farms selling over 50% of their production and engaged in milk processing (number), Zajecar District (RS)
- Farms selling over 50% of their production and engaged in fruit and vegetable processing (number), Zajecar District (RS)
- Farms selling over 50% of their production and engaged in brandy making (number), Zajecar District (RS)
- Farms selling over 50% of their production and engaged in other activities connected with food processing (number), Zajecar District (RS)
- Farms selling over 50% of their production and engaged in other activities (number), Zajecar District (RS)
- Farmers selling at green markets, Zajecar District (RS)
- Farmers, Zajecar District (RS)
- N of organic farmers per municipality, Zajecar District (RS)
- Farms selling over 50% of their production and engaged in farm tourism (number), Zajecar District (RS)
- Average number of land plots per landowner, Galicia (ES)
- Average amount of land per owner, Galicia (ES)
- Utilized agricultural area (UAA) per farm (ha) (2023), Zajecar District (RS)
- Farms selling over 50% of their production and engaged in aquaculture, Zajecar District (RS)
- N of homesteads (not registered as farmers) per municipality, Troyan (BG)
- Crop products supply chain, Zajecar District (RS)
- Eggs supply chain, Zajecar District (RS)
- Fish supply chain, Zajecar District (RS)
- Flour supply chain, Zajecar District (RS)
- Fruits, vegetables, mushrooms and processed foods supply chain, Zajecar District (RS)
- Honey supply chain, Zajecar District (RS)
- Meat and meat products supply chain, Zajecar District (RS)





		<ul style="list-style-type: none"> • Milk and dairy products supply chain, Zajecar District (RS) • Green markets, Zajecar District (RS) • Farmers selling online, Zajecar District (RS) • Buyers of products from farms, Zajecar District (RS) • Commercial establishments offering local food, Troyan (BG) • Farms selling over 50% of their production and engaged in wood processing, Zajecar District (RS) • Farms selling over 50% of their production and engaged in handicrafts, Zajecar District (RS)
Forestry	<ul style="list-style-type: none"> • Forest Type, 3-yearly • Forest Proportion of Land (%) • Tree Cover Density, 3-yearly • Small Woody Features, 3-yearly • Dominant Leaf Type 	<ul style="list-style-type: none"> • Farms selling over 50% of their production and engaged in forestry services, Zajecar District (RS)

Source: own elaboration.



4. Distributed and diversified production systems

The rural function “Distributed and Diversified Production Systems” reflects the capacity of rural areas to support a wide array of economic activities beyond traditional agriculture.

- At the **European level**, indicators are largely spatial and structural. Points of Interest (banks, retail shops, restaurants, cinemas, cultural and industrial facilities) mapped with grid and accessibility data offer a snapshot of service availability and economic density. These indicators are valuable in identifying urban-rural gradients, evaluating proximity to key services, and informing regional spatial planning. The inclusion of metrics such as unemployment proportion, sectoral employment shares, and tourism accommodation capacity adds a socio-economic dimension, supporting macro-level assessments of economic diversity and labour market composition.
- The **Living Lab indicators**, on the other hand, provide deeper insights into local dynamics of commercial activity, entrepreneurship, tourism, and consumption. These indicators capture important aspects such as the vitality of the local economy, consumption habits, and the interaction between local production and service provision. They reflect both the density and diversity of economic activities and offer the kind of granularity that is essential for evaluating the resilience and adaptability of rural production systems.

A particularly relevant dimension is the integration of qualitative and behavioural data, such as local product consumption trends and business perceptions, which adds nuance to the quantitative metrics and helps capture territorial specificities and emerging practices—critical elements in designing effective rural economic strategies.



Table 6. European and living labs indicators related to “Distributed and diversified production systems” function.

Topic	European Indicators	Living Lab Indicators
Economic Infrastructure	<ul style="list-style-type: none"> Banks. Points of Interest, Grid, and Accessibility 	
Cultural and Leisure Infrastructure	<ul style="list-style-type: none"> Cinema. Points of Interest, Grid, and Accessibility Culture. Points of Interest 	
Retail and Commercial Fabric	<ul style="list-style-type: none"> Retail Shops. Points of Interest, Grid, and Accessibility Commercial Activities. Points of Interest 	<ul style="list-style-type: none"> Commercial establishments offering local food, Troyan (BG) Commercial activity: active premises and empty premises, Osona (ES) Commercial Point of Interest, Osona (ES) Commercial Heatmap, Osona (ES) Local trade consumption, Osona (ES) NO Local Products Consumption, Osona (ES) OCCASIONAL Local Products Consumption, Osona (ES)
Entrepreneurial & Industrial Capacity	<ul style="list-style-type: none"> Industry. Points of Interest 	<ul style="list-style-type: none"> Employment rate % of secondary sector - industry and constructions, Upper Carinthia (AT) Survey with enterprises, Woj. Świętokrzyskie (PL)
Socioeconomic Performance	<ul style="list-style-type: none"> Unemployment Proportion PIB per capita 	
Workforce Structure	<ul style="list-style-type: none"> Agriculture Sector Workers Proportion Construction Sector Workers Proportion General Service Workers Proportion 	<ul style="list-style-type: none"> Businesses and public facilities by sector category, Upper Carinthia (AT)
Tourism and Service Economy	<ul style="list-style-type: none"> Restauration. Points of Interest Touristic Assets. Points of Interest Touristic Information. Points of Interest Tourism capacity in rooms per LAU2 	<ul style="list-style-type: none"> N of Restaurants, Troyan (BG) Eterprises in gastronomy in Radomski subregion, Woj. Świętokrzyskie (PL) Tourism Point of Interest, Osona (ES) Tourism Heatmap, Osona (ES) N of hotels and accommodations per municipality, Troyan (BG) Enterprises in accommodation in Radomski subregion, Woj. Świętokrzyskie (PL)

Source: own elaboration.



5. Social capital / cultural assets & cooperative institutions

The rural function “Social capital, cultural assets and cooperative institutions” plays a fundamental role in shaping the resilience, cohesion, and long-term sustainability of rural territories. It reflects the capacity of communities to build trust, foster shared identities, promote civic participation, and ensure equitable access to cultural and public services. The indicator set—comprising both European-level and local Living Lab data—provides a rich and multi-faceted framework for assessing this crucial yet often intangible dimension of rural development.

- At the **European level**, the indicators focus primarily on demographic and structural aspects. Data on population size and density, age distribution, birth and death rates, and migration trends offer insights into demographic change, ageing, and depopulation—factors that **directly** influence the strength of social networks and institutional capacity in rural areas. In addition, indicators on the distribution and accessibility of schools, cultural venues, healthcare services, and public amenities are central to understanding territorial equity and the baseline conditions for social wellbeing.
- Complementing this, **Living Lab indicators** add depth by capturing local relational, cultural, and institutional dynamics. These include measures of civic engagement, perceived quality of public spaces, community participation in decision-making, and the availability of social and **cultural** infrastructure. Other indicators assess housing stress, neighbourhood quality of life, and walkability, all of which reflect how inclusive, safe, and liveable a rural area is for its residents.

What makes this indicator set particularly valuable is its combination of objective and subjective dimensions. It goes beyond the mere presence of services to explore how they are experienced, valued, and accessed by different groups in the community. This is especially relevant for the function that deals with collective identity, social cohesion, and the self-organizing capacity of local communities.



Table 7. European and LL indicators related to “Social capital / cultural assets & cooperative institutions” function.

Topic	European Indicators	Living Lab Indicators
<p>Demographic Dynamics</p>	<ul style="list-style-type: none"> • Population (1981, 1991, 2001, 2011, 2021) • Population growth 1981-2021 • Density • Density Growth 2011-2021 	<ul style="list-style-type: none"> • Szydłowiecki LAU population by age from 1995 to 2023, Woj. Świętokrzyskie (PL) • Population, North Karelia (FI) • Świętokrzyskie_Region population from 2005 to 2022, Woj. Świętokrzyskie (PL) • Świętokrzyskie_Density of population from 2005 to 2022, Woj. Świętokrzyskie (PL) • Świętokrzyskie_Share of the population at pre-working age / working age / post-working age (2005–2022), Woj. Świętokrzyskie (PL) • Annual change rate (%), Zajecar District (RS) • Ageing index, Zajecar District (RS) • Old age dependency ratio, Zajecar District (RS) • Structural dependency index, Zajecar District (RS)
<p>Gender & Social Equity</p>	<ul style="list-style-type: none"> • Women employment proportion • Women and men unemployment difference • Female Disadvantage Index (FemDI) • Female Achievement Index (FemAI) 	<ul style="list-style-type: none"> • N of women farmers receiving CAP payments, Troyan (BG)
<p>Migration & Diversity</p>	<ul style="list-style-type: none"> • Crude rate of net migration • Migration population proportion 	<ul style="list-style-type: none"> • Educational migration, Rhein Hunsrück (DE) • Percent of population with foreign mother tongue, North Karelia (FI) • Population outflow by age group and destination, Monmouthshire (UK)





<p>Cultural Capital</p>	<ul style="list-style-type: none"> • Cinema. Points of Interest, Grid, and Accessibility • Culture. Points of Interest 	<ul style="list-style-type: none"> • Culture. Points of Interest, Osona (ES) • Cultural Heatmap, Osona (ES) • Green and recreational spaces, Osona (ES)
<p>Education & Human Capital</p>	<ul style="list-style-type: none"> • Tertiary education level (25-64) (%) • Secondary education level (25-64) (%) • Early school leaving (18-24) (%) 	<ul style="list-style-type: none"> • Participation in groups or associations, Osona (ES) • Participation in courses, Osona (ES) • NO/YES Courses Participation, Osona (ES)
<p>Institutional Quality & Governance</p>	<ul style="list-style-type: none"> • Quality of Government Index 	<ul style="list-style-type: none"> • NO/YES Associations Participation, Osona (ES) • Survey with enterprises, Woj. Świętokrzyskie (PL) • Companies by sector category, Upper Carinthia (AT) • Public institutions, Upper Carinthia (AT) • Awareness and Participation in Municipal Activities, Osona (ES) • YES/NO EMD Following (App, Social Media, All), Osona (ES) • Degree of knowledge of neighbours, Osona (ES) • Comments on the local area / leisure (questions: “Do you have any comment about the area in which you live in?”; “Why do you spend time here?”), Monmouthshire (UK)
<p>Socioeconomic & Territorial Conditions</p>		<ul style="list-style-type: none"> • Prioritization of Settlements for the Implementation of the 'Model Settlement' Instrument, Galicia (ES) • Perception of the quality of life, Osona (ES) • Local trade consumption, Osona (ES) • Ratio between landowners and inhabitants at municipal level, Galicia (ES) • CAP direct payments / beneficiaries / SMEs / farmers, Troyan (BG) • Seva Divisions, Experiment Subdivision, Osona (ES) • Employment rate % of tertiary sector - services and public administration, Upper Carinthia (AT)

Source: own elaboration.





4. Database Development and Integration in the RUSTIK Viewer

4.1. Aim

Starting from the widely acknowledged reality that rural regions often face challenges in accessing and using relevant data, the RUSTIK project has taken an innovative approach to overcome this limitation. Through the work of the Living Labs, and by identifying European novel data sources, the project has successfully explored new methodologies to access a wide range of data and bring it together across multiple levels – from local sources to national and EU-wide datasets. This has allowed for a more comprehensive and nuanced understanding of rural areas' functions and their ongoing transitions.

In this context, the RUSTIK Viewer has been developed as a key tool to support the integration, visualization, and dissemination of data. It enables Living Labs to showcase the results of their experiments in a clear and accessible way, while also making valuable rural data available to a broader audience, including policymakers, researchers, and the general public. By facilitating access to structured and multi-scalar information, the Viewer plays a central role in enhancing evidence-based decision-making and reinforcing the visibility and strategic relevance of rural areas across Europe.

This section offers insights into the status of data integration into the Viewer, showing the progress made by the project in consolidating diverse data sources and transforming them into a shared, user-friendly platform for rural intelligence.





4.2. Conceptualization of the RUSTIK Viewer

The [RUSTIK Viewer](#), also referred to as the RUSTIK Information System, is a user-friendly tool developed to support all Living Labs in collecting, organizing, and visualizing data relevant to their experiments. It also offers external users the ability to gather relevant data for rural regions and monitor project progress in a transparent and accessible way.

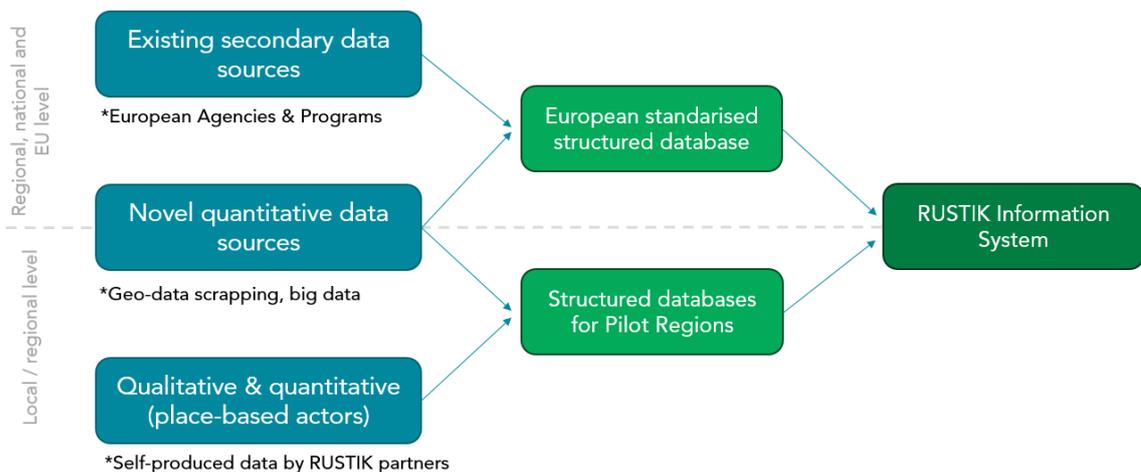
Built as an analytical interface, the Viewer provides centralized access to datasets from the RUSTIK Database. It enables stakeholders to gain comprehensive insights into rural transitions and functional rural areas by integrating data across multiple levels—from a central EU system down to localized, pilot region systems. These regional systems are populated with data generated during the Living Labs' experimentation processes.

The system follows a user-centric design philosophy, with a strong emphasis on intuitive navigation, anticipatory features, and clear visual cues. Its interface is designed to be self-explanatory, ensuring ease of use for diverse user profiles, from local practitioners to policymakers and researchers.

The RUSTIK Viewer's core function is to help Living Labs consolidate the information essential for tackling their local and regional challenges. It is also a valuable asset for regional and EU-level stakeholders, offering insights that can inform policy development and future research.

MCRIT is responsible for maintaining the system and managing data uploads, ensuring that the Viewer remains updated and aligned with the project's evolving needs.

Figure 1. Conceptualization of the RUSTIK Viewer, and structure of databases



Source: own elaboration.





4.3. Status of European database integration

The European-level database developed for the RUSTIK project currently integrates more than 100 harmonized spatial indicators structured around the three transition areas: socioeconomic, environmental, and digital. Approximately 60% of the indicators correspond to the socioeconomic transition, 35% to the environmental transition, and the remaining 5% are associated with the digital transition. These indicators are organized thematically into sections reflecting the main dimensions of each transition, as presented in the following table.

Table 8. Sections for the RUSTIK Transitions in the European Core

Socioeconomic Transition	Environmental Transition	Digital Transition
Demographics and Population	Climate Resilience	Digital infrastructure
Social Welfare and Inclusion	Natural Resources and Heritage Conservation	Digital skills
Facilities and Community Development	Land Cover and Land Use	Digital transformation
Employment and Economic Development	Environment	
Community Engagement and Governance	Sustainable Development	

Source: own elaboration.

The **socioeconomic transition** section compiles:

- Longitudinal demographic data from Eurostat (population by LAU2 for the years 1981, 1991, 2001, 2011, and 2021).
- Derived demographic metrics such as population growth and density change.
- Migration dynamics, captured through net migration rates and the proportion of migrant population.
- Gender disparities and labour market conditions are analysed through composite indicators such as the Female Disadvantage Index (FemDI) and Female Achievement Index (FemAI), sourced from DG REGIO, as well as disaggregated statistics on women’s employment and gender unemployment gaps (Eurostat, 2022). Employment structure is further detailed with sector-specific proportions (agriculture, industry, construction, services, financial, and tourism-related sectors), compiled from the Joint Research Centre and DG REGIO.
- Proportion of population aged 25–64 with tertiary and secondary education, and early school leaving rates for the 18–24 age group, derived from Eurostat (2022)





- Accessibility to public services and facilities—such as primary and secondary schools, hospitals, pharmacies, doctors, retail, cinemas, banks, and train stations—is measured through a set of availability grids, distance layers, and accessibility indices provided by the ESPON PROFECY database (2022).
- Additional geospatial layers on facilities and points of interest are integrated from OpenStreetMap (2024), classified by activity domain: commercial, cultural, health, industrial, natural, gastronomic, general services, sports, and tourism.

The **environmental transition** section integrates multiple layers related to land cover, climate resilience, and ecological conservation:

- Land cover and land use data are primarily sourced from the Copernicus Global Land Service (LUISA), including high-resolution raster and vector layers such as CLC+ Backbone, Urban Atlas, Imperviousness Density and Change, Forest Type, Tree Cover Density, and Grassland extent and variation (reference year 2018, updated triennially).
- These are complemented by conservation designations such as Natura 2000 and Emerald Network protected areas, mountain areas, and riparian zones.
- Climate-related risks are covered through indicators from the European Environmental Agency (EEA), including the average and projected meteorological forest fire danger (1981–2010 and 2041–2071, under RCP 4.5 and RCP 8.5 scenarios), areas burnt by wildfires, changes in precipitation patterns (summer/winter), and drought frequency projections.
- Vegetation dynamics are described with daily satellite-derived vegetation indices (NDVI, LAI, PPI, Leaf Area Index) from EEA and Copernicus, complemented with phenology and quality flag layers.
- Air quality is included with average concentrations of PM2.5, PM10, and ozone (EEA, 2023).
- On the energy front, indicators on solar, hydropower, and onshore production potentials are derived from the JRC (2023), supporting the evaluation of renewable energy deployment at regional level.

The **digital transition** section, though less populated in the current release, incorporates:

- Layers from the JRC (2023) on the spatial availability of high-speed fixed and mobile broadband networks. These serve as proxies for digital connectivity and the enabling infrastructure for digital transformation processes in rural and intermediate territories.

This section of the database is an advanced tool in terms of thematic coverage, granularity, and harmonization. During the last section of the RUSTIK project, it will remain open to further enhancement if needed. The database will continue to be improved as new indicators become available or are developed.





4.4. Status of Living Lab databases integration

The integration of local-level data generated through the Living Labs is currently underway. This process represents the second layer of the RUSTIK data architecture and aims to enhance the European core database with territorialized, context-specific information stemming from experimentation and participatory research carried out in each pilot region.

At this stage, substantial progress has been made in gathering and structuring the datasets provided by Living Lab partners. The indicators collected vary significantly in thematic scope and granularity, reflecting both the diversity of regional contexts and the priorities addressed by each Living Lab.

- The **Troyan-Aprilitzi-Ugarchin Living Lab (Bulgaria)** has contributed a broad set of indicators centred on rural development and agri-food systems. These include detailed figures on beneficiaries and SMEs receiving payments under the Common Agricultural Policy (CAP) gender-disaggregated data on women farmers, organic and livestock farming patterns, and the presence of homesteads and apiaries at the municipal level. Economic activity is captured through NACE Rev. 2 classifications for agriculture, tourism infrastructure (e.g., accommodations and restaurants), and commercial establishments offering local food. This dataset enables a multidimensional analysis of CAP influence, food system localization, and economic diversification in rural areas.
- In **Nockregion-Oberkärnten (Austria)**, the Living Lab has focused on employment structure by sector (primary, secondary, tertiary), availability of agricultural holdings (INVEKOS/IACS), and sectoral categorization of local enterprises and public facilities. These indicators are aligned with the aim of understanding labour dynamics and institutional presence in mountainous regions, where multifunctionality of rural economies is often a strategic necessity.
- The **Sant Miquel de Balenyà Living Lab (Spain)** has provided a mix of environmental, social, and perceptual indicators. These include energy efficiency certifications, spatial distribution of commercial premises (active vs. empty), accessibility to green and recreational spaces, exposure to noise and air pollution, and the availability of climate shelters. Importantly, it also includes data derived from participatory processes such as perceived quality of life, social participation, knowledge of neighbours, and support for local commerce—reflecting a strong integration of quantitative and qualitative insights for quality-of-life assessments.
- The **Galicia Living Lab (Spain)** has contributed detailed cadastral and land ownership indicators at municipal and parish levels. These include ratios between landowners and residents, average land plot size and fragmentation, and prioritization schemes for the implementation of rural development instruments such as “model settlements.” This information supports spatialized strategies for land consolidation and rural repopulation.
- In **Województwo Mazowieckie (Poland)**, particularly in the Szydłowiecki subregion, the data received includes historical population structures by age from 1995 to 2023 at LAU and settlement levels, as well as sector-specific enterprise data for gastronomy and accommodation. Additionally, survey-based data on enterprise needs and limitations has been gathered, which contributes to understanding local business dynamics and barriers to development.





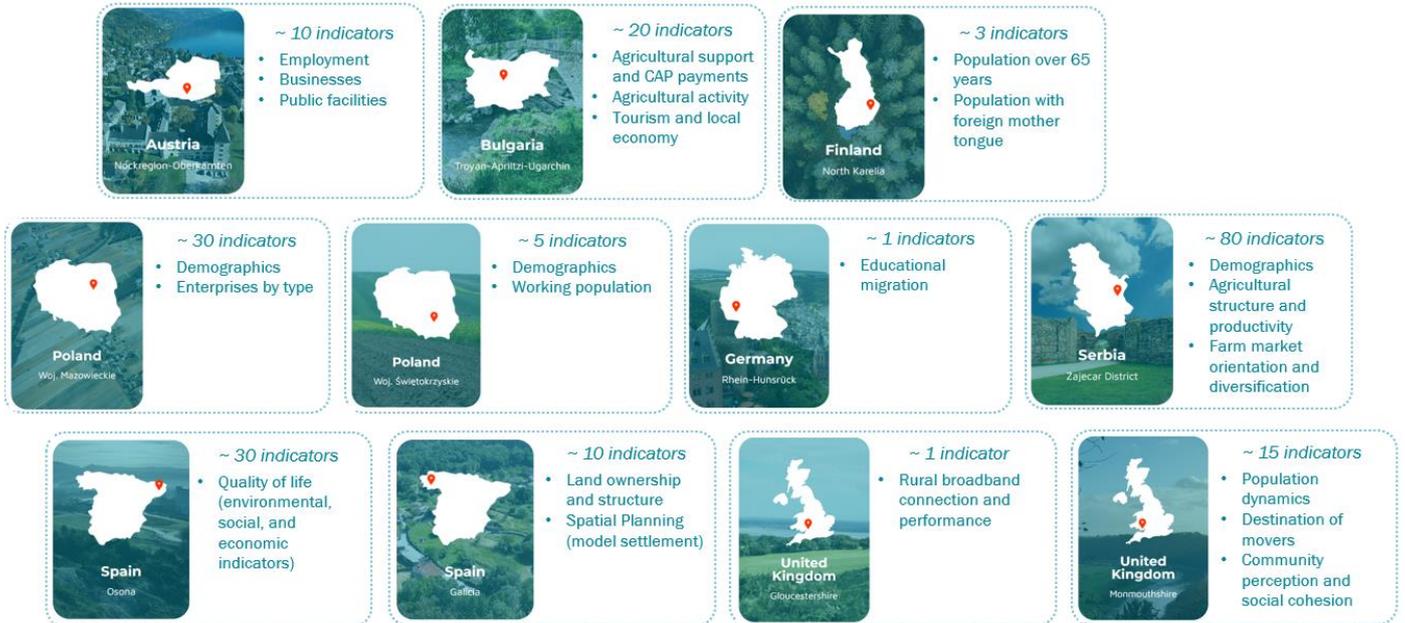
- The **Zaječar District Living Lab (Serbia)** has submitted a comprehensive dataset on agricultural performance and diversification. Indicators include aging and dependency ratios, utilized agricultural area and livestock units per farm, annual work units (AWU), standard output (SO), and the share of farms engaged in other gainful activities (OGA). There is also highly detailed information on specific types of food processing, forestry services, tourism, and supply chains (e.g. meat, honey, flour, aquaculture), as well as commercial links between producers, processors, SMEs, and hospitality establishments. This dataset enables a detailed mapping of rural value chains and their territorial embeddedness.
- The **Monmouthshire Living Lab (United Kingdom)** has focused on demographic mobility patterns by age cohort, including inter- and intra-regional movements. It also includes perception-based data regarding leisure, the local area, and settlement-level delineations using Lower Layer Super Output Areas (LSOAs) from 2011 and 2021. This dataset is particularly valuable for analysing rural-urban dynamics, youth outmigration, and place attachment.
- The **Rhein-Hunsrück Living Lab (Germany)** explores demographic change through the lens of educational migration, focusing on population ageing and youth mobility. The main dataset analyses net migration flows of individuals aged 18–24 between 2014 and 2021, expressed per 1,000 inhabitants of the same age group. The data, sourced from Bertelsmann Stiftung (2023), is spatially disaggregated at LAU 1 level and offers insights into local retention and outmigration trends.
- The **North Karelia Living Lab (Finland)** provides a demographic snapshot of rural Finland, with particular attention to population ageing and cultural diversity. The dataset, compiled by Statistics Finland (2023), includes the total population, the share of residents aged over 65, and the percentage of inhabitants with a foreign mother tongue as of 2022. The data is disaggregated at LAU level and accessible via the Finnish statistical portal. These indicators allow for an in-depth understanding of demographic pressures, social integration challenges, and the ageing dynamics in peripheral territories, making them essential for planning inclusive public services and long-term territorial resilience strategies.
- The **Gloucestershire Living Lab (United Kingdom)** addresses the digital transition through an analysis of broadband infrastructure in rural areas, using 2022 data on fixed broadband speed and availability sourced from Ofcom. The indicator covers all six districts within the county, though the Living Lab activities will exclude the predominantly urban areas of Gloucester and Cheltenham. By mapping average broadband performance at the LAU level, the dataset enables the identification of rural zones where digital connectivity remains limited. This focus is key for tackling spatial disparities and shaping more inclusive digital development policies tailored to non-urban contexts.
- The **Świętokrzyskie Voivodeship Living Lab (Poland)** provides an extensive temporal and spatial dataset to explore demographic dynamics in rural areas. Spanning from 2005 to 2022, and sourced from the Polish Central Statistical Office, the indicators cover population figures, density, and the age structure of inhabitants, including pre-working, working, and post-working age groups. The data is disaggregated at LAU level and enables the tracking of long-term trends in population ageing, workforce shrinkage, and rural depopulation. Thanks to its longitudinal consistency, this dataset supports strategic reflection on demographic resilience and the adaptation of local policies to emerging socio-economic pressures.





So far, Living Labs have delivered data to the RUSTIK Viewer. Until the end of the RUSTIK project (Month, 2026), Living Labs will continue collecting, processing, validating, and formatting additional data that will be included in the RUSTIK Viewer.

Figure 2. Local Data from Living Labs



Source: own elaboration.





4.5. Next Steps

This section presents the roadmap that has guided so far, the development of the RUSTIK Viewer, with an overview of the main phases of work from data collection to integration, final refinement, and long-term maintenance. Communication and dissemination of the platform is a transversal phase throughout the project.

For each of the steps, the status of the task is identified. All tasks will be finalized towards the delivery of D2.4, foreseen for end of 2025 (December).

Collection of European-Level Datasets (finalized)

The first phase involved compiling datasets relevant at the European level to establish the baseline information infrastructure of the Viewer. This activity began in the previous year and is now largely concluded, with more than 100 indicators compiled. Although minor additions may still be incorporated where appropriate, the structure of the European dataset layer is considered stable and ready for continued use.

Submission of Living Lab Data (in process)

In March 2025, all Living Labs were invited to submit the local data they have gathered and used in their experiments for potential inclusion in the Viewer. The response was broadly positive, with most Living Labs providing relevant data aligned with the scope of their local experimentation. The remaining Living Labs are expected to identify and submit their data in the coming weeks, ensuring that the Viewer includes contributions from all Living Labs across the project.

Integration of Living Lab Data (in process)

The integration of the Living Lab datasets is currently underway. This process involves reviewing each dataset for consistency and suitability for inclusion in the Viewer. The data is then reformatted and incorporated into the system. This is a technical and iterative phase, requiring coordination with the Living Labs to resolve potential issues in structure or content.

Living Lab Experiment Sliders (in process)

In response to concerns expressed by some Living Labs regarding the suitability of their data for geographic visualisation or public dissemination, a complementary approach is being implemented. The Viewer will feature dedicated experiment sliders for each Lab. These components will summarise the scope and focus of the experiment, describe the methodology used, identify the types of data collected, and present the main findings. The information will be based on the Joint Final Results Reports.

Final Adjustments and System Refinement (pending)

The final stage of development, planned for the last quarter of the year, will focus on refining the Viewer based on internal testing and user feedback. Adjustments may include interface improvements, minor bug fixes, and optimisation of performance. This phase will also finalise the visual and functional design.





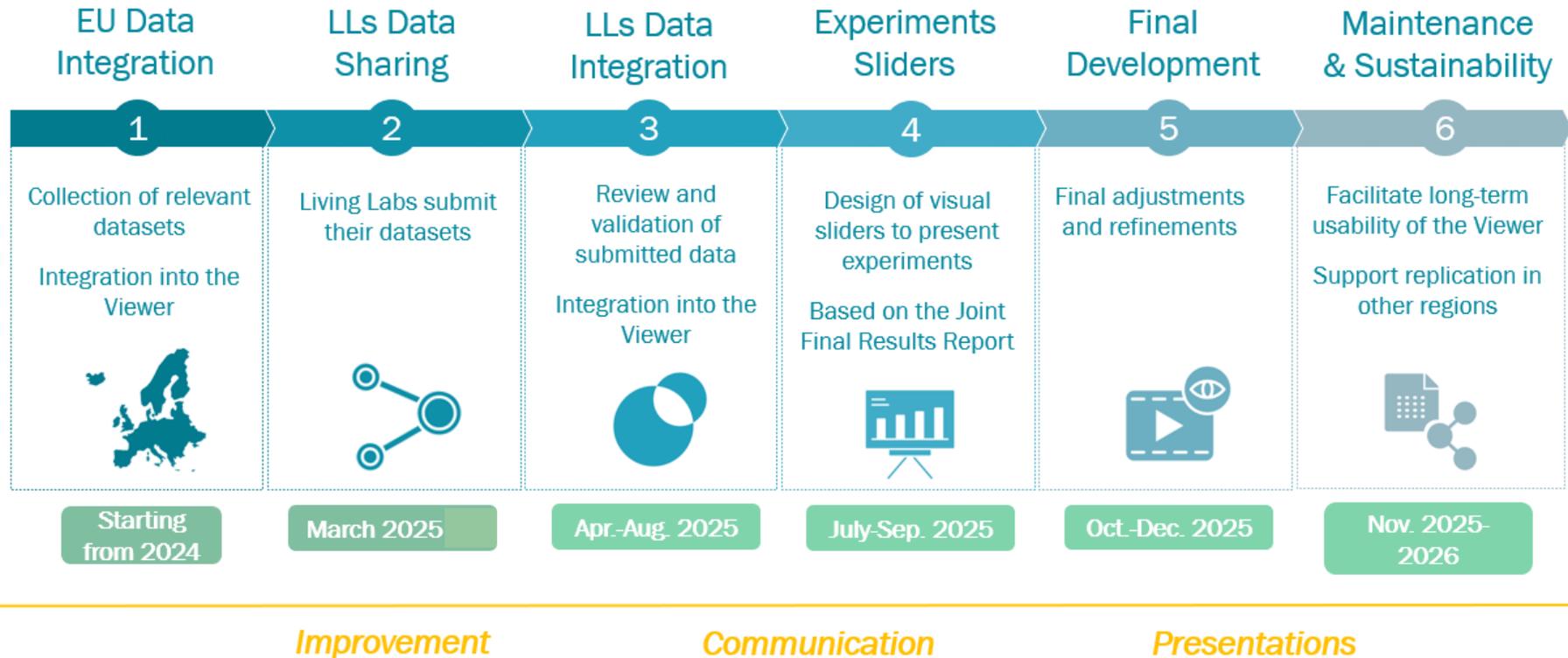
Maintenance and Sustainability protocol (pending)

To ensure long-term viability, the project team will define a strategy for maintaining and updating the Viewer after the conclusion of the project. This includes preparing technical documentation, establishing update protocols, and exploring opportunities for replication in other geographic or thematic contexts. The goal is to facilitate the reuse of the tool in future research or policy initiatives, both within and beyond the RUSTIK framework. Information on maintenance and sustainability will be included in Deliverable D2.4.





Figure 3. Roadmap for RUSTIK Viewer Development



Source: own elaboration.



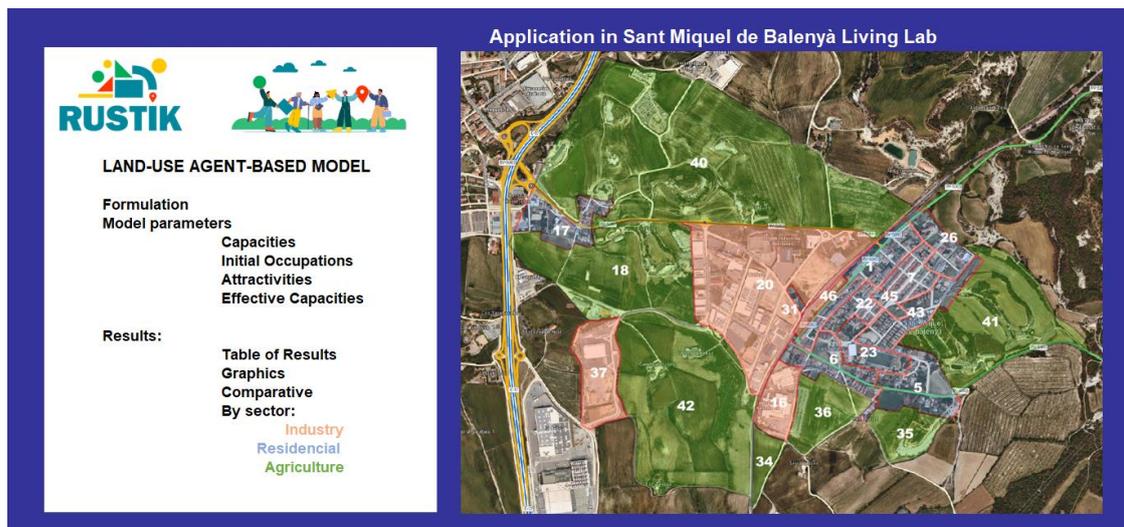
5. Land-use Agent-based Model: testing the RUSTIK database with selected Living Labs

5.1. Aim

As part of the RUSTIK project, we have developed a pilot application of agent-based modelling to examine how land-use patterns evolve over time in rural areas undergoing digital, environmental, and socioeconomic transitions. We have used the LL database of the Sant Miquel de Balenyà Living Lab to investigate how novel algorithms based on Artificial Intelligence may generate new data and/or estimate missing data useful for policy-impact assessment.

The agent-based model developed is a land-use model where the location of new activities in each zone is modelled by a non-linear stochastic algorithm (Nonlinear Polya Urn Model and Self-Organizing Process). Zones are classified into residential, industrial, agricultural and forest, and agents into households, factories and farms. The probability a given agent or activity is located into a zone depends on the initial conditions (how many activities are located) and the boundary conditions (the carrying capacity of each zone). The model assumes positive externalities or agglomeration economies at the beginning of transformation and negative externalities and diseconomies close to the capacity thresholds.

Figure 4. RUSTIK Land-use Agent-based Model. Front Page

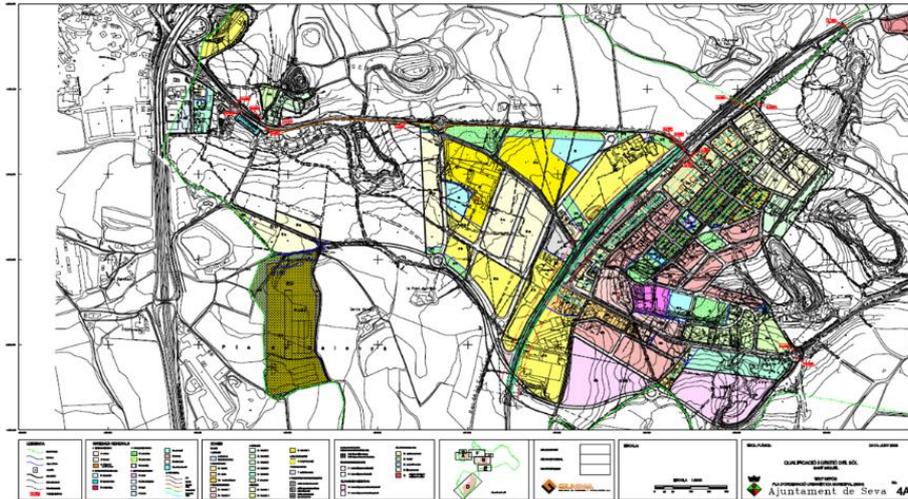


Source: own elaboration.

Data concerning the zoning system and capacities is based on the Land Use Plan (2004), and data concerning activities located in each zone overtime was computed by investigating satellite images. Based on this data, the parameters of the probability functions were calibrated for the pilot application in the Osona Living Lab. Both data from satellite images and the statistical calibration should be carried out by Artificial Algorithms (AI). We propose to apply Neuronal Networks Algorithms for this calibration, assuming large datasets.

Figure 5. Inputs of the model

Land-use categories from the 2004 Land Use Plan.



Current land-use patterns, as identified through satellite imagery.



Source: own elaboration.

In terms of software, we used an MS EXCEL spreadsheet for the pilot, in order to facilitate the use of the model by non-expert modellers. Commercial and open-source applications like NetLogo, Repast Symphony, and others based on microsimulation of Cellular Automata algorithms were tested but not considered useful for the pilot. It is possible to integrate the non-linear stochastic (NLS) formulation in these software packages, however. Because MS EXCEL is a user-friendly and transparent tool, the pilot can be useful as a pedagogic tool. The NLS algorithm and the AI data calibration process, as well as the design of the whole pilot, can be replicated.

The model will be tested in other Living Labs to assess its applicability in different contexts. The objective is to understand what elements can be replicated, how the model can be adapted, and what modifications may be required for successful implementation in other Living Labs.

Rather than producing deterministic forecasts, the model is designed to support exploratory analysis and strategic reflection. It allows users to test how initial conditions, land-use regulations, and targeted interventions (e.g. subsidies or zoning reforms) influence long-term spatial patterns. This makes it a valuable tool for ex-ante policy impact assessment, particularly in rural contexts where granular data or dynamic models are scarce. It aims at testing plausible development trajectories and identifying leverage points for public action.

5.2. Background of Agent-based Models (ABM)

Agent-Based Models (ABMs) are a simulation methodology used to explore complex systems composed of interacting entities—called agents—that follow simple behavioural rules. The origins of ABM can be traced back to fields such as game theory, artificial intelligence, and computational social science, with seminal contributions from researchers like Thomas Schelling, John Conway, and Joshua Epstein¹. Over time, ABMs have evolved into a versatile tool for studying dynamic, adaptive, and emergent phenomena in socio-ecological, urban, and economic systems.

A defining feature of ABMs is their bottom-up approach: rather than imposing aggregate equations or centralized control, ABMs allow patterns to emerge from the decentralized actions and interactions of individual agents. This makes them particularly powerful for understanding non-linear, path-dependent, and spatially differentiated processes.

In land-use and territorial modelling, ABMs have been applied extensively to simulate:

- **Rural-to-urban migration:** capturing the decision-making processes behind population shifts based on employment, service availability, environmental factors, and social ties.
- **Urban growth and sprawl:** modelling how cities expand through decentralized development decisions and spatial feedback.
- **Socioeconomic dynamics:** investigating inequalities, gentrification, and access to housing or services.
- **Land-use change:** examining transitions from agriculture and forest to residential or industrial uses under varying scenarios and policy frameworks.

A notable example in this domain is the **SLUMS (Slumulation)** model, which simulates the emergence of informal settlements based on agent decisions under constraints like income, policy, and infrastructure. Other ABMs have adapted classical theories such as the gravity model or the urban transition model to simulate migration flows, accessibility dynamics, or service provision.

Several platforms have been developed to support ABM construction and simulation, including:

Table 9. ABM Platforms

Platform	Type	Language	Users	Strengths	Weaknesses
NetLogo	Desktop	NetLogo	Researchers, educators, students	Intuitive interface, ideal for conceptual models	Limited scalability for large/real-world models
Mesa	Desktop	Python	Data scientists, researchers	Python integration, interactive, flexible	Less intuitive for beginners

¹ Seminal contributions to ABM development include Schelling’s segregation model (1971), Conway’s *Game of Life* (Gardner, 1970), and Epstein & Axtell’s *Sugarscape* model (1996).

Platform	Type	Language	Users	Strengths	Weaknesses
GAMA	Desktop	GAML (custom language)	Urban planners, ecologists	GIS integration, spatial modelling capabilities	Steeper learning curve
Repast	Desktop	Java, Python, C#	Advanced researchers	High scalability, cloud/supercomputing support	Complex setup
AnyLogic Cloud	Online	Java, AnyLogic script	Analysts, engineers, researchers	Versatile, collaborative, supports multiple paradigms	Limited features without paid license
Simul8 Online	Online	Visual (no code)	Business users, educators	Easy to use, process-oriented	Not designed for advanced ABM
NetLogo Web	Online	NetLogo	Educators, students	Accessible, easy to start	Reduced functionality vs. desktop
MASON (Cloud)	Online	Java	Developers, researchers	Highly scalable, flexible for large simulations	Requires advanced setup
AgentSheets/AgentCubes	Online	Visual (drag-and-drop)	Educators, hobbyists	Beginner-friendly, interactive ABM	Limited for scientific modelling

Source: own elaboration.

In the context of the RUSTIK project, our model builds on this lineage of ABM development by incorporating the Polya process—a stochastic mechanism emphasizing reinforcement and path dependency. While implemented in Excel for transparency and accessibility, the model retains key characteristics of agent-based thinking: decentralized decision-making, sensitivity to initial conditions, and emergent dynamics. It contributes to the broader ABM tradition by offering a lightweight yet theoretically grounded tool to support scenario-building and policy reflection in rural land-use transitions.

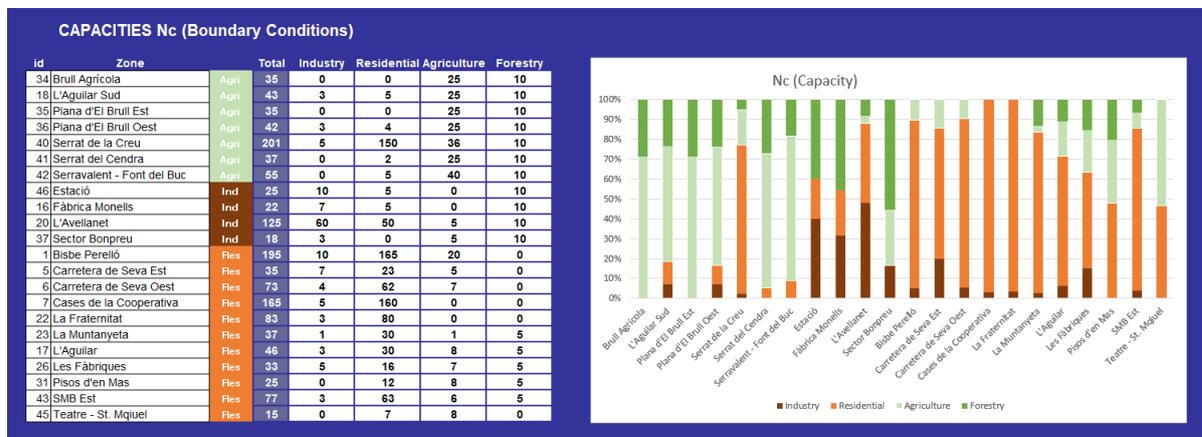
5.3. Model Inputs

In the model, each land use (residential, industrial, agriculture, forestry) competes for space under these conditions (or parameters). The parameters are presented in the following figure, and described later:

Capacities	Initial Occupation	Attractivities	Effective Capacities
<p>Regulatory/planning limits on maximum development. Boundary conditions (e.g. urban planning, zoning laws).</p> <p>Land-use categories were derived from the 2004 Land Use Plan.</p>	<p>Land-use types currently present in each zone (baseline state).</p> <p>Based on current land-use patterns, as identified through satellite imagery.</p>	<p>Context-specific desirability of each land-use (e.g. accessibility, policy support).</p> <p>Values were determined through statistical calibration.</p>	<p>Adjustment of formal capacities based on real-world constraints (e.g. terrain, community acceptance).</p> <p>Values were adjusted using statistical calibration.</p>

→ **Capacities:** represent the potential land-use capacities established by spatial and urban planning frameworks. These define the maximum extent to which a certain land use can occur in a given area (e.g., zoning regulations, environmental constraints). In the case of our applied model, we used the land-use categories derived from the 2004 Land-Use Plan of Sant Miquel de Balenyà (Osona).

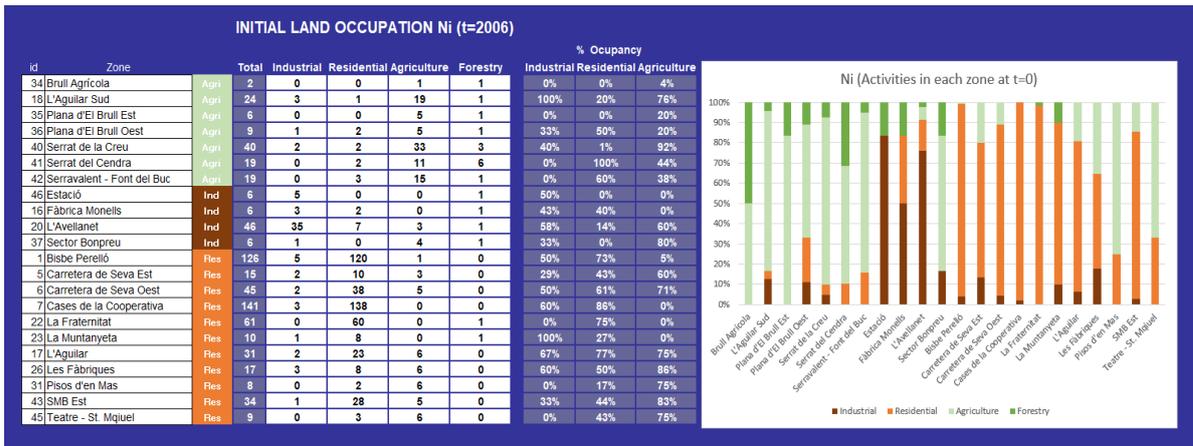
Figure 6. Capacities



Source: own elaboration.

→ **Initial Occupations:** these refer to the actual land uses currently present in each zone. They provide the initial state of the system and influence the model's evolution due to the path-dependent nature of the process. In our model, initial occupations were based on current land-use patterns, as identified through satellite imagery.

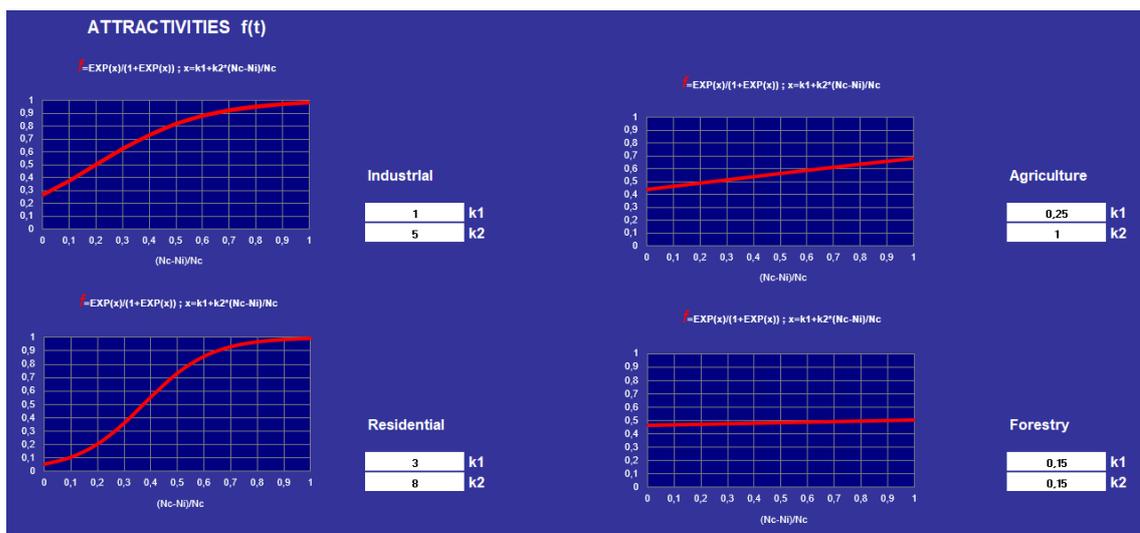
Figure 7. Initial Land Occupation



Source: own elaboration.

→ **Attractivities:** represent the intrinsic and context-dependent attractiveness of each land use type in a given zone. Attractiveness may reflect factors such as accessibility, environmental quality, policy support, or proximity to other uses. In the model, attractivities values were determined through statistical calibration².

Figure 8. Attractivities



Source: own elaboration.

→ **Effective Capacities:** combine formal capacities with contextual or social-environmental constraints that may enhance or limit actual development (e.g., terrain suitability, public acceptance, environmental regulations). Effective capacities were determined using statistical calibration.

² *Statistical calibration* refers to the process of adjusting model parameters so that the model's outputs closely match observed data. This helps ensure the model behaves realistically based on empirical evidence.

Figure 9. Interdependence Factors

Interdependence Table. Limiting Factors.

Limiting uses	Limiting Factors			
	Industry	Residential	Agriculture	Forestry
Industry	1	0.5	0.7	0.8
Residential	0.5	1	0.8	0.9
Agriculture	0.7	0.8	1	1
Forestry	0.8	0.9	1	1

id	Zone		EFFECTIVE CAPACITIES (Ne)			
			Industrial	Residential	Agriculture	Forestry
34	Brull Agrícola	Agri	0	0	25	10
18	L'Aguliar Sud	Agri	3	5	25	10
35	Plana d'El Brull Est	Agri	0	0	25	10
36	Plana d'El Brull Oest	Agri	3	4	25	10
40	Serrat de la Creu	Agri	5	146	35	10
41	Serrat del Cendra	Agri	0	2	25	10
42	Serravalent - Font del Buc	Agri	0	5	40	10
46	Estació	Ind	10	3	0	6
16	Fàbrica Monells	Ind	7	3	0	7
20	L'Avellanet	Ind	60	26	3	5
37	Sector Bonpreu	Ind	3	0	4	8
1	Bisbe Perelló	Res	10	157	19	0
5	Carretera de Seva Est	Res	7	18	4	0
6	Carretera de Seva Oest	Res	4	58	7	0
7	Cases de la Cooperativa	Res	5	155	0	0
22	La Fraternitat	Res	3	77	0	0
23	La Muntanyeta	Res	1	29	1	5
17	L'Aguliar	Res	3	28	7	5
26	Les Fàbriques	Res	5	14	6	4
31	Pisos d'en Mas	Res	0	12	8	5
43	SMB Est	Res	3	61	6	5
45	Teatre - St. Miquel	Res	0	7	8	0

Capacities are reduced based on limiting factors and the relative proportion of dependent uses in the zone

Source: own elaboration.

5.4. Model Operation

The model simulates land-use change using an adaptation of the Polya process algorithm, as formulated in Goerge Polya work on increasing returns and path dependence³. It operates over a sequence of 50 iterations (representing events, new activities located in the zone, not necessarily attached to a particular regular lapses of time). The probability that a land-use type increases in each zone rises with its current presence, introducing self-reinforcing dynamics. The dynamics are designed to capture self-reinforcing behaviour: the more a land use is already present in a zone, the more likely it is to expand further.

At each iteration n , for each zone and each land use type $i = 1, 2, \dots, N$, the model follows the stochastic updating rule.

Let the total number of "balls" (land-use units) at the start be:

$$w = \sum_{i=1}^N S_{i,1}$$

where $S_{i,1}$ is the initial number of units (cells, parcels) occupied by land-use i .

At time n , define the random variable $b_{i,n}(x)$ as:

$$b_{i,n}(x) = \begin{cases} 1 & \text{with probability } q_{i,n}(x) \\ 0 & \text{with probability } 1 - q_{i,n}(x) \end{cases}$$

This represents the probabilistic selection of land-use i for an additional unit in iteration n , where $q_{i,n}(x)$ is the attraction probability for land-use i in zone X .

The total count of units of land-use i is updated as:

$$b_{i,n+1} = b_{i,n} + b_{i,n}(x)$$

Dividing by the total number of units ($w + n$), we obtain the evolution of the proportion $X_{i,n}$:

$$X_{i,n+1} = X_{i,n} + \frac{1}{w + n} (b_{i,n}(x) - X_{i,n})$$

This formula introduces non-linear, path-dependent dynamics: the presence of land-use i at time n affects its probability of expansion at time $n + 1$, reinforcing initial advantages or spatial lock-ins.

Each run of the model produces different outcomes due to the probabilistic nature of the selection process. Residential and industrial uses are modelled as more sensitive to contextual factors and proximity to other uses, while agriculture and forestry are considered more inertial.

After 50 iterations (events), the model outputs the final distribution of land uses in each zone:

³ Pólya, G. (1930). *Sur quelques points de la théorie des probabilités*. Annales de l'Institut Henri Poincaré, 1(2), 117 – 161.

See also: Arthur, W. B. (1994). *Increasing Returns and Path Dependence in the Economy*. University of Michigan Press.

$$N_i(t = 50)$$

where N_i is the number of units of land-use i after 50 events.



Figure 10. Polya Process Algorithm

LAND-USE AGENT-BASED MODEL

POLYA PROCESS ALGORITHM

Adapted from W. Brian Arthur (Foreword by Kenneth J. Arrow). "Increasing returns and path dependence in the economy"

Let the total activities initially be $w = \sum b_i$
At time n , define the random variable

$$\beta_n^i(x) = \begin{cases} 1 & \text{with probability } A_n^i(x) \\ 0 & \text{with probability } 1 - A_n^i(x) \end{cases} \quad i = 1, \dots, N$$

Then additions of i -types of activities to the urn follow the dynamics

$$b_{n+1} = b_n + \beta_n^i(X_n), \quad i = 1, \dots, N$$

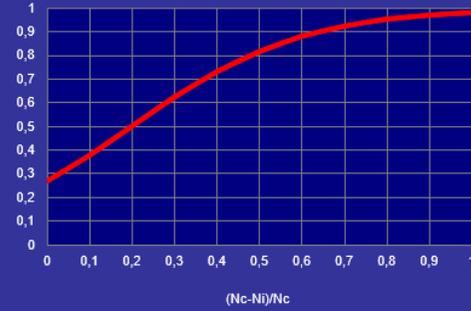
Dividing through the total activities ($w+n-1$), the evolution of the proportion of i -types

$$X_{n+1}^i = X_n^i + 1/(w+n) (\beta_n^i(X_n) - X_n^i) \quad n=1, 2, \dots$$

Each run of the model yields different results (the final number of uses $N(t=50)N(t=50)$, in each zone)

A_i = Atractividad de la zona i
 N_i = Number of uses zone i
 N_c = Theoretican Capacity to host different uses zone i
 N_e = Effective Capacity to host uses in each zone i
 p = Total number of location alternatives ($p=20$)
 α = Parámetro (si $\alpha=1$, proceso lineal)
 f = factor reducing the attractivity

$$f = \frac{1}{1 + \exp(x)}; \quad x = k_1 + k_2 * (N_c - N_i) / N_e$$



$$A_i = f \cdot \frac{N_i^\alpha}{\sum_{j=1}^p N_j^\alpha}$$

Source: own elaboration.





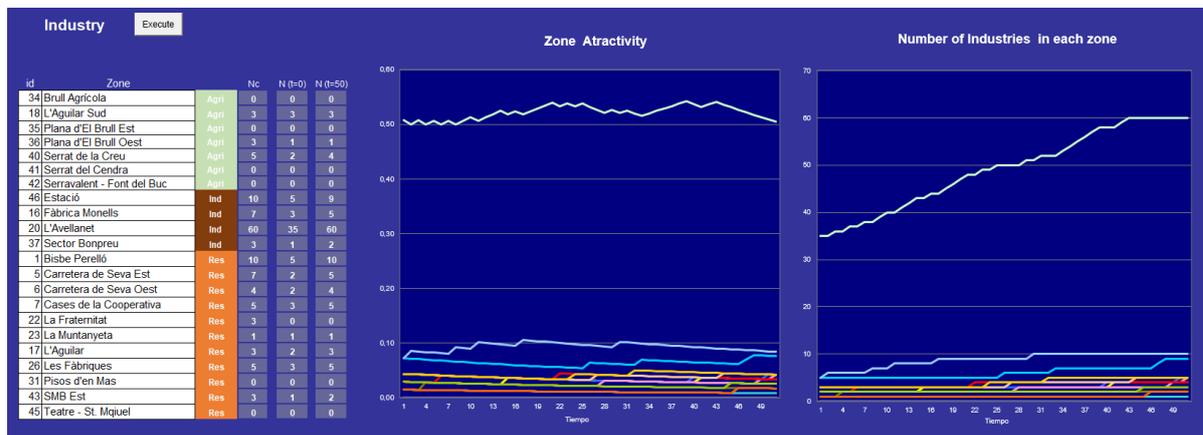
5.5. Model Outputs

The model produces the following outputs:

- **Tables of results:** indicating the distribution of land uses across zones after 50 steps.
- **Graphs by sector:** showing the temporal evolution and spatial distribution of each land use (industry, residential, agriculture, forestry).
- **Comparative scenarios:** through multiple runs, the influence of varying initial conditions or policy interventions (e.g., subsidies) can be explored.

Most industrial growth concentrates in a few zones with initially higher attractivity (e.g., "l'Estació", "l'Avellanet"). These areas exhibit both increasing attractivity values and growing industrial counts, demonstrating the self-reinforcing nature of the model. Other zones show minimal change, suggesting path dependence and limited spontaneous diversification.

Figure 11. Table of Results for Industrial Sector



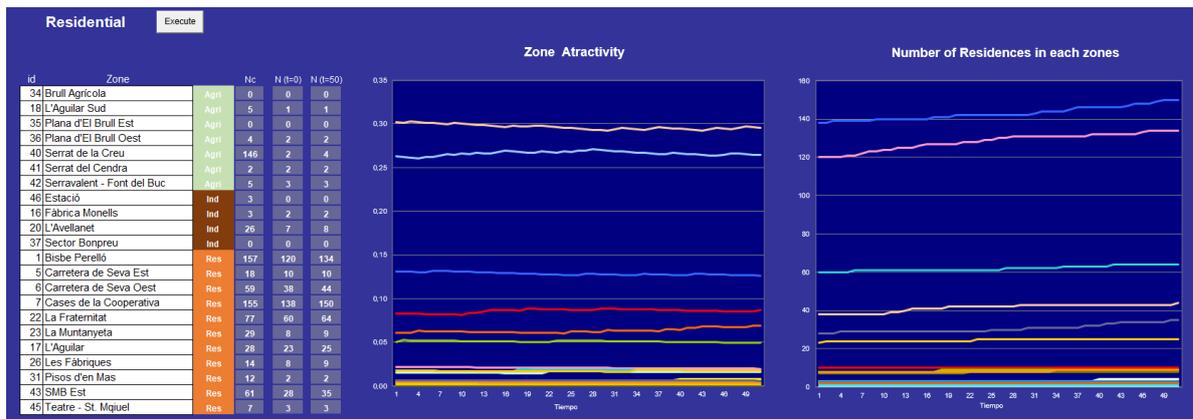
Source: own elaboration.

Residential land use tends to expand steadily across a broader set of zones. The most significant increases are observed in areas that already had strong residential presence, such as "Cases de la Cooperativa" and "La Fraternitat", aligning with the reinforcement effect embedded in the model.





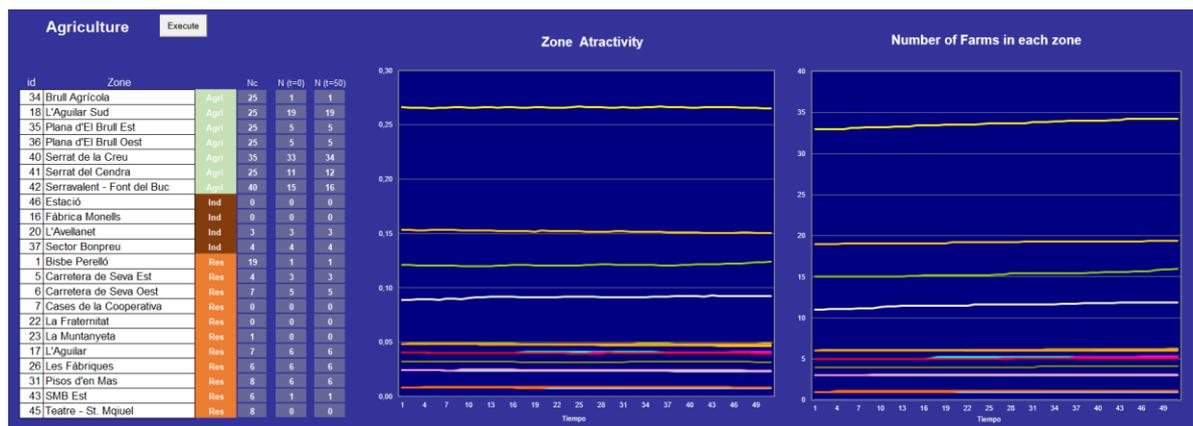
Figure 12. Table of Results for Residential Sector



Source: own elaboration.

Agricultural uses show a slow but steady increase, primarily concentrated in zones already classified as agricultural (e.g., "L'Aguliar Sud" and " Serrat de la Creu "). The attractivity levels remain relatively stable, with little competition from other uses in these peripheral zones.

Figure 13. Table of Results for Agricultural Sector



Source: own elaboration.

Forestry land use shows the least change over time. Most zones maintain their initial number of forest plots. This could reflect low attractivity or low pressure for land-use conversion in forested areas under current model parameters.





Figure 14. Table of Results for Forestry Sector



Source: own elaboration.

The following table summarizes the net changes for each land use type by zone. Positive changes (e.g., +25 in "l'Avellanet" for Industry) highlight where growth was concentrated, while negative values (e.g., -4 for Residential in "Teatre - St. Miquel") indicate zones where land was converted to another use.

Figure 15. Summary Table of Results

id	Zona	Executa	CAPACITY					INITIAL OCCUPATION (N = 0)					FINAL OCCUPATION (N = 50)				
			Total	Industry	Residential	Agriculture	Forestry	Total	Industry	Residential	Agriculture	Forestry	Total	Industry	Residential	Agriculture	Forestry
34	Brull Agrícola	Agri	35	0	0	25	10	2	0	0	1	1	11	0	0	1	10
18	L'Aguilar Sud	Agri	43	3	5	25	10	24	3	1	19	1	33	3	1	19	10
35	Plana d'El Brull Est	Agri	35	0	0	25	10	6	0	0	5	1	15	0	0	5	10
36	Plana d'El Brull Oest	Agri	42	3	4	25	10	9	1	2	5	1	18	1	2	5	10
40	Serrat de la Creu	Agri	196	5	146	35	10	40	2	2	33	3	52	4	4	34	10
41	Serrat del Cendra	Agri	37	0	2	25	10	19	0	2	11	6	24	0	2	12	10
42	Serravalent - Font del Buc	Agri	55	0	5	40	10	19	0	3	15	1	29	0	3	16	10
46	Estació	Ind	19	10	3	0	6	6	5	0	0	1	15	9	0	0	6
16	Fàbrica Monells	Ind	17	7	3	0	7	6	3	2	0	1	14	5	2	0	7
20	L'Avellanet	Ind	94	60	26	3	5	46	35	7	3	1	76	60	8	3	5
37	Sector Bonpreu	Ind	16	3	0	4	8	6	1	0	4	1	14	2	0	4	8
1	Bisbe Parelló	Res	186	10	157	19	0	126	5	120	1	0	145	10	134	1	0
5	Carretera de Seva Est	Res	29	7	18	4	0	15	2	10	3	0	18	5	10	3	0
6	Carretera de Seva Oest	Res	69	4	59	7	0	45	2	38	5	0	53	4	44	5	0
7	Cases de la Cooperativa	Res	160	5	155	0	0	141	3	138	0	0	155	5	150	0	0
22	La Fraternitat	Res	80	3	77	0	0	61	0	60	0	1	64	0	64	0	0
23	La Muntanyeta	Res	36	1	29	1	5	10	1	8	0	1	15	1	9	0	5
17	L'Aguilar	Res	43	3	28	7	5	31	2	23	6	0	34	3	25	6	0
26	Les Fàbriques	Res	29	5	14	6	4	17	3	8	6	0	20	5	9	6	0
31	Pisos d'en Mas	Res	25	0	12	8	5	8	0	2	6	0	8	0	2	6	0
43	SMB Est	Res	74	3	61	6	5	34	1	28	5	0	38	2	35	1	0
45	Teatre - St. Miquel	Res	15	0	7	8	0	9	0	3	6	0	3	0	3	0	0

Source: own elaboration.

To end with, the model also produces another way of representing the results. In the following figure, the top graph shows which land uses increased or decreased by zone after 50 iterations. The bottom graph shows final land-use composition by zone. The graphs make it visually clear that residential and industrial growth dominates the simulation, with agriculture and forestry more stable or declining in specific areas.





Figure 16. Summary Table and Graphs for Land Use Changes



Source: own elaboration.





5.6. Interpretation and Use

The insights described below are informed by the test simulations presented in the previous section. While the model is exploratory by nature, the outputs offer valuable indications of how different land uses behave under self-reinforcing dynamics and spatial constraints.

The model is not intended to produce deterministic forecasts, but rather to facilitate exploratory analysis, scenario testing, and strategic reflection. It provides a flexible, theory-informed framework that enables stakeholders to:

- **Trace the evolution of land-use patterns** over time under varying assumptions and interventions. For example, in the industry simulation (Figure 11), growth clusters emerged in zones with initially high attractivity, reinforcing initial conditions.
- **Assess the critical role of initial legal and spatial conditions** in shaping long-term territorial trajectories. Zones pre-defined as residential or industrial saw much greater transformation, highlighting the importance of zoning and land allocation in the first step.
- **Understand reinforcing dynamics**, such as how existing land uses tend to attract similar future uses, leading to spatial lock-in or the formation of “critical mass”. The residential simulation (Figure 12) shows how some zones consistently grew faster due to their initial higher density, demonstrating self-reinforcing growth.
- **Identify spillover effects**, whereby areas that reach their capacity catalyse activity in adjacent zones. As seen in Figure 16, once the most attractive zones become saturated, growth shifts toward adjacent areas – especially visible in mid-growth zones.
- **Detect zones at risk** of persistent underuse or unsustainable overdevelopment. Some peripheral zones remained underutilized (e.g. “Teatre – St. Miquel”), while others accumulated intense growth (e.g., “Cases de la Cooperativa”), possibly beyond their carrying capacity.
- **Explore the potential of public interventions**—such as zoning changes or incentives—to shift development paths. Although not included in the current run, the model architecture allows re-running scenarios under alternative policy inputs, e.g. subsidies or zoning reclassifications.

Unlike digital twins or GIS-based simulations—which may rely on highly detailed data and often follow rigid logic structures—this model offers a conceptual but operationally useful alternative. Its lower data dependency makes it especially suitable for rural or data-scarce contexts.

Beyond analytical functions, the model also has pedagogical and participatory applications, supporting:

- **Capacity building** and training on spatial planning dynamics,
- **Participatory planning processes** with communities and stakeholders, and
- **"What-if" experimentation** to co-design and evaluate policy options.

Ultimately, this tool complements traditional spatial models by fostering a deeper understanding of territorial processes, empowering users to engage critically and creatively with the challenges of rural development.





5.7. Potential contributions of Machine Learning to the Agent-based Modelling approach

While the RUSTIK Agent-Based Model (ABM) has been designed to operate with limited and locally sourced data—making it particularly suitable for rural and data-scarce contexts—the integration of Machine Learning (ML) techniques could potentially open new avenues to enhance its robustness, adaptability, and exploratory potential. The application of AI could support several phases of the ABM lifecycle, following frameworks identified in recent systematic reviews⁴.

Enhancing Calibration and Parameter Estimation

The calibration of model parameters (e.g. attractivities, effective capacities, interdependencies) is key to credible outputs. Traditionally, calibration has relied on manual estimation or statistical regressions applied to satellite-derived land-use patterns. However, supervised ML algorithms—such as Artificial Neural Networks (ANNs) or Gradient Boosted Trees—could potentially automate and improve this process by learning non-linear relationships between spatial features (e.g. elevation, proximity to services, historical land use) and land-use transitions.

That said, their successful implementation would depend on access to large, high-quality training datasets. In rural contexts, such datasets often do not exist. While satellite imagery is one source, ground-truthing, harmonized time series, cadastral integration, and policy annotations would often be required. Thus, ML-enhanced calibration might only be feasible in Living Labs where multi-temporal spatial datasets and annotated observations are already available or could be constructed.

Estimating Missing or Latent Data

Data imputation and augmentation could be another area where ML proves useful, particularly for variables such as accessibility, land suitability, or informal land uses, which are often missing or inconsistently reported in rural areas. Approaches such as unsupervised learning, clustering, or dimensionality reduction could help infer missing values or expose latent spatial structures that enrich zoning dynamics. In line with the reviewed methodologies, models trained in well-documented regions could be adapted to others via transfer learning, supporting cross-Living Lab learning.

However, this raises issues of generalizability and context sensitivity: ML models trained in one region might not capture socio-spatial idiosyncrasies elsewhere unless adapted carefully. This would further underscore the importance of combining algorithmic outputs with local knowledge and participatory validation processes to ensure contextual relevance and legitimacy.

⁴ Nikitas, A., Papaioannou, P., & Zahariadis, T. (2024). Artificial intelligence and agent-based modelling: A systematic review of cooperative approaches. *Transactions in GIS*. <https://doi.org/10.1111/tgis.13152>





Emerging Synergies: AI and ABM as Complementary Tools

The systematic review identified ten distinct ways in which AI could cooperate with ABM—from pre-processing to real-time feedback loops (Nikitas et al., 2024). Key synergies might include:

- Pattern detection in historical land-use trajectories to seed ABM initial conditions.
- Quality assessment of simulated scenarios, allowing for iterative selection of more plausible outcomes.
- Reinforcement learning layers that dynamically adjust agents' decision rules based on observed land-use dynamics.

These AI–ABM hybrids could enable the model to learn and adapt, potentially producing emergent behaviours that more closely mimic real-world evolutions—particularly in complex, urbanising rural contexts.

Limitations and Integration Challenges

Despite its potential, integrating AI into the ABM framework would introduce several technical and conceptual challenges:

- **Data demands:** AI approaches typically require extensive, labelled datasets for training. For rural Living Labs, this would often imply significant investment in data collection, cleaning, and harmonization.
- **Black-box opacity:** Unlike the transparent stochastic formulation currently in use, more complex AI systems may reduce stakeholder trust unless supported by explainable AI (XAI) frameworks.
- **Technical capacity:** Many Living Labs currently lack the resources or expertise to implement and interpret advanced AI workflows. Effective integration would need to be paired with capacity-building efforts and user-friendly toolkits.

A Complementary—not-Substitutive—Role

Consistent with the RUSTIK project's emphasis on user-friendliness and replicability, AI could serve as a modular extension of the ABM—not as its replacement. For instance, AI could:

- Support the pre-processing of spatial and temporal datasets.
- Serve in the post-analysis of simulation outputs, identifying patterns or anomalies.
- Help generate attractivity maps or decision heuristics for agents within the Excel toolkit or a modular plugin.

In summary, integrating AI techniques into the RUSTIK framework could open up opportunities for data-driven insight, cross-Living Lab learning, and scenario exploration. However, these possibilities would need to be carefully weighed against issues of data availability, transparency, and contextual fit—especially in settings where technical capacity and data infrastructure remain limited.





5.8. Assessing the Replicability Potential of the Agent-based Model Across Living Labs

Replicability Potential and Adaptability of the Model

The model has been designed to be easily adapted to other rural or low-data contexts. Its implementation in Microsoft Excel makes it transparent, easy to modify, and accessible to a wide range of users, including non-specialists. This format is particularly suitable for small-scale pilots, training sessions, and participatory planning exercises.

The structure of the model allows straightforward adjustments to reflect different territorial conditions or planning questions. It also supports pedagogical uses in contexts where more complex simulation tools are impractical.

Other platforms such as NetLogo, Repast, and GAMA were considered, but Excel was selected due to its lower complexity, easier learning curve, and greater flexibility for the intended use. Looking forward, the model could be expanded with components for more advanced calibration or integration with spatial tools where appropriate.

Survey on Stakeholder Interest and Feasibility of Replication in Living Labs

In order to gather feedback on the developed model and to better understand its replicability potential, a questionnaire targeted at the Living Labs was developed. The questionnaire was structured into three main sections: *Interest and Familiarity*, *Analytical Relevance*, and *Policy Relevance*.

The objectives of the survey were:

- Assess familiarity with agent-based and land-use modelling.
- Evaluate the analytical and policy relevance of the model.
- Identify potential land-use conflicts and tipping points in the Living Labs.
- Gather insights on potential interventions.
- Understand replicability conditions and support needed.

All Living Labs, except Sant Miquel de Balenyà, answered the questionnaire (13 answers). The Sant Miquel de Balenyà's Living Lab did not participate in the questionnaire as the model has already been implemented using its database.

The following section presents the results of the survey.





1. Interest and Familiarity

Familiarity with agent-based modelling

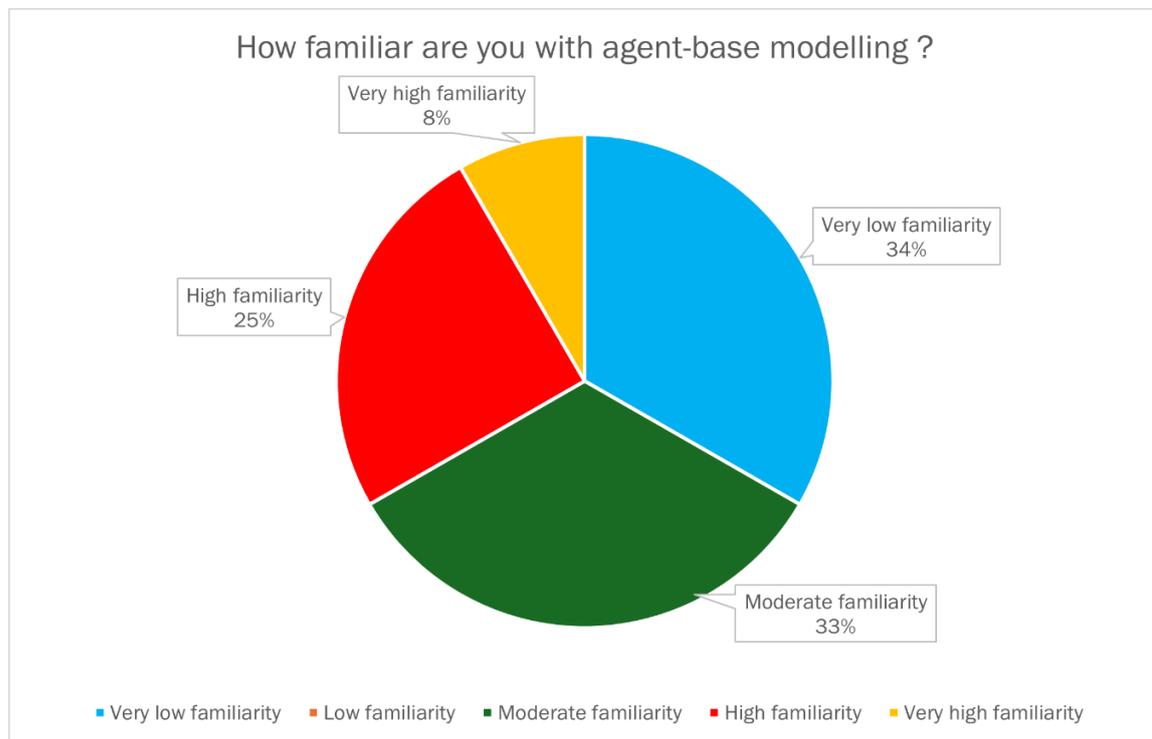
To assess the current level of knowledge regarding agent-based modelling across the Living Labs, a specific question was included in the questionnaire. Respondents were asked to rate their familiarity on a scale from 1 (not familiar) to 5 (very familiar).

Out of the 13 responses:

- 3 Living Labs indicated they are not familiar at all with ABM,
- 3 responses scored a 2, suggesting very limited familiarity,
- 4 responses selected 3, pointing to a moderate or neutral level of familiarity,
- 3 Living Labs reported a high level of familiarity, selecting 5 – Very familiar.

These results suggest that while a small number of Living Labs have advanced knowledge of agent-based modelling, the majority possess only basic to moderate awareness of this methodology. The presence of both highly experienced and less experienced Living Labs could offer opportunities for peer-to-peer learning, especially if more tailored support is provided to those with limited exposure.

Figure 17. How familiar are you with agent-based modelling? (Survey: 13 answers)



Source: own elaboration.





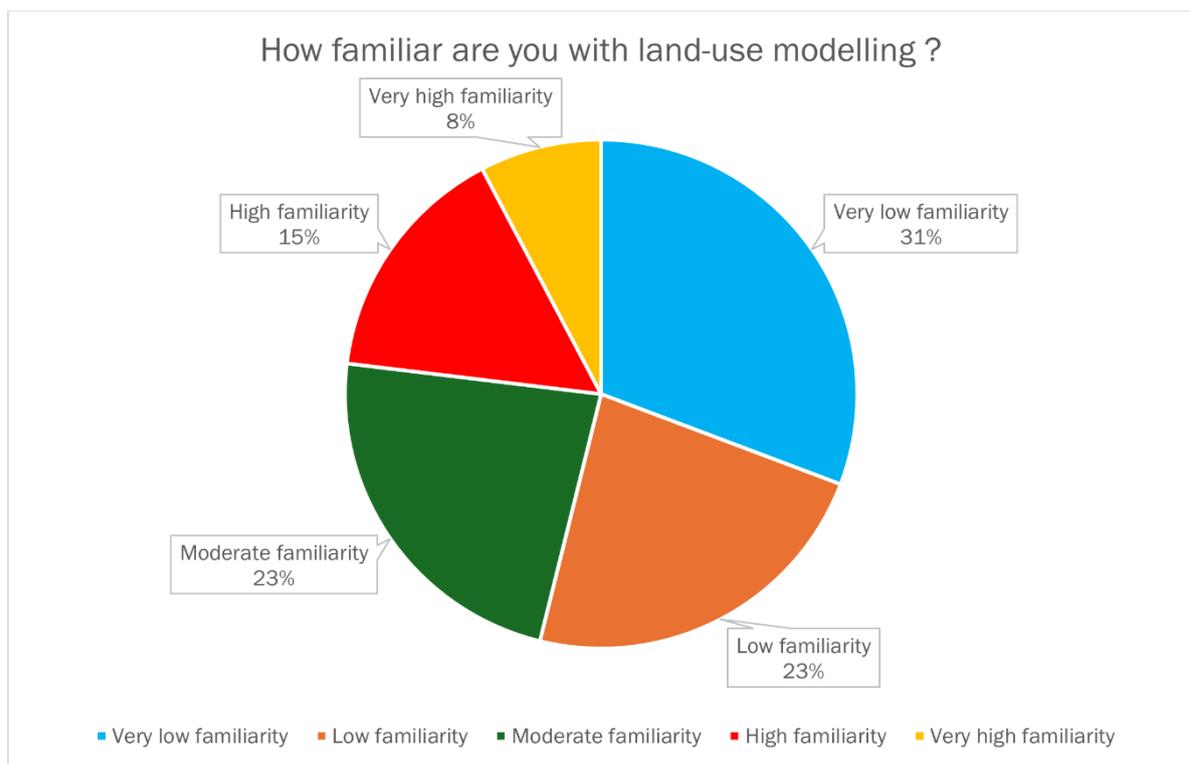
Familiarity with land-use modelling

Land-use modelling was included in the survey, using the same scale-based technique applied to the previous question. The results indicate that, overall, land-use modelling is not widely known or used across the network.

Only a small number of Living Labs demonstrated high familiarity with the topic, with just one Living Lab selecting the highest score (5) and two others indicating a relatively strong background (score 4). In contrast, a significant share of responses clustered in the lower end of the scale. Four Living Labs explicitly stated no familiarity at all, while several others rated their knowledge as very limited or basic (scores 2 and 3).

The pattern of responses suggests that, unlike more widely disseminated methodologies, land-use modelling remains relatively underexplored within many of the Living Labs. This may reflect the technical complexity of common land-use models, the lack of exposure to spatial simulation tools, or limited access or interest to training opportunities in this area.

Figure 18. How familiar are you with land-use modelling? (Survey: 13 answers)



Source: own elaboration.





Utilization of simulation models to forecast rural change

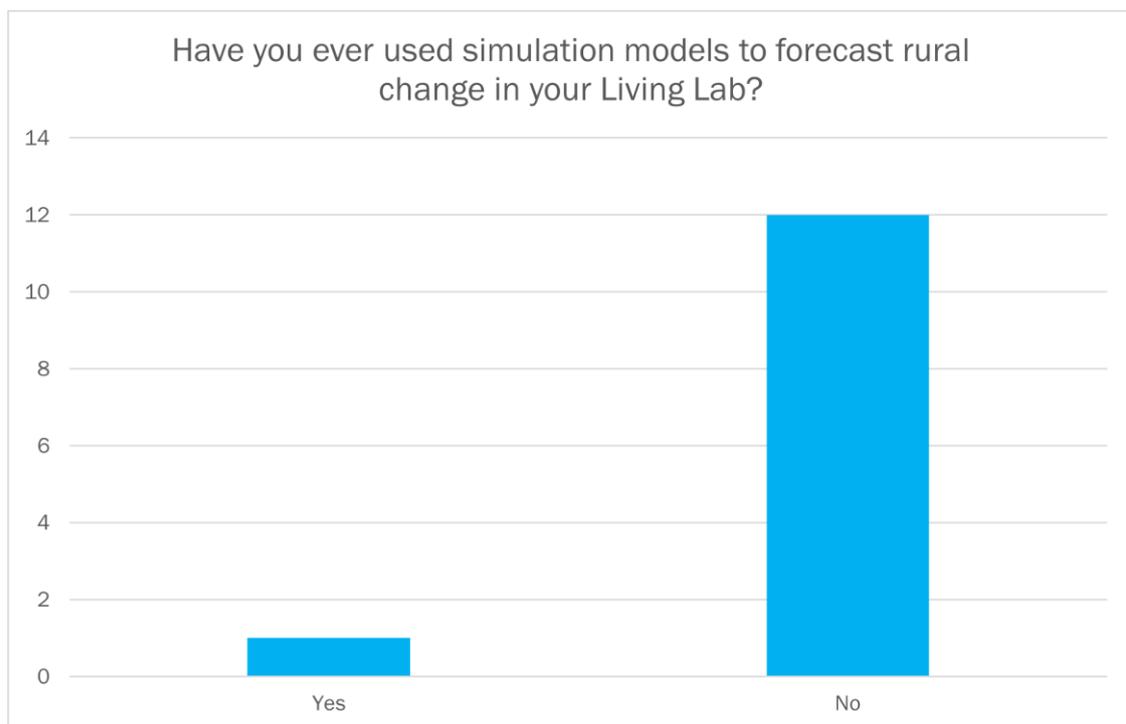
In this case we wanted to explore the practical application of simulation models within the Living Labs, specifically in relation to forecasting rural change. The objective was to understand whether modelling tools are currently being used to anticipate transformations in land use, demographics, economy, or environmental dynamics.

The responses to this question were particularly clear: 12 out of 13 Living Labs reported never having used simulation models for this purpose. Only one Living Lab indicated prior experience with applying such tools in their local context.

While some Living Labs show varying degrees of familiarity with modelling approaches, such as agent-based or land-use modelling, this has not, in most cases, translated into real-world application within territorial processes or planning efforts.

Introducing accessible modelling platforms, showcasing concrete use cases, and fostering interdisciplinary collaboration may all contribute to closing this implementation gap and encouraging more widespread and effective use of simulation methods to guide rural development.

Figure 19. Have you ever used simulation models to forecast rural change in your Living Lab? (Survey: 13 answers)



Source: own elaboration.





2. Analytical and Policy Relevance

Most relevant transitions to explore in the Living Labs territories using a simulation model

When asked about the types of transitions most relevant to explore through simulation models, the vast majority of Living Labs pointed to the socioeconomic dimension as the central area of interest. Out of the 13 collected responses, 10 explicitly identified socioeconomic transitions as the most pressing or promising topic for model-based exploration in their respective regions.

Other types of transitions were mentioned more marginally. Only two Living Labs referred to environmental transitions, and one response highlighted digital transition as a relevant focus. This clear prioritisation reflects the nature of their Living Lab experiments and shows that many LLs are currently grappling with or anticipating structural changes in rural economies, demographics, employment, and service provision, and are seeking tools to help them navigate and better understand these complex dynamics.

Hypotheses to test through such a simulation model

Living Labs were asked to provide tentative hypothesis that could be tested through similar types of simulation models. Many hypotheses touch upon demographic change, particularly the outmigration of young people and the factors that may influence their retention or return. Respondents expressed interest in simulating how variables such as land-use diversification, housing types, and access to services and employment might affect the settlement patterns of younger and working-age populations.

Agricultural transitions also emerged as a prominent theme. Multiple Living Labs proposed hypotheses related to changes in farming systems, such as the evolution of cattle vs. sheep farming, and how these shifts may influence both employment and environmental outcomes. Other hypotheses focused on land-use dynamics, irrigation practices, and the implications of agricultural intensification on biodiversity—particularly within Natura 2000 sites.

Several responses addressed broader territorial and economic transformations, including the development of short food supply chains, the integration of agriculture with tourism, and the settlement of businesses in rural areas. One response proposed modelling the impact of natural resource availability on the structure of local economies, while another explored the uptake of broadband grants and their effect on connectivity rates—a clear link to digital transition processes.

Important land-use conflicts or tipping points to forecast

Regarding land-use or tipping points, a recurring theme, according to the answers given, is the conflict between agricultural land use and competing demands, particularly the growing pressure to install photovoltaic infrastructure on farmland. This tension raises concerns over how to balance renewable energy production with food security and the preservation of productive rural landscapes. Similarly, several respondents noted ongoing or anticipated land-use shifts, such as the abandonment of agricultural or grassland areas in favour of spontaneous forest expansion, which can lead to ecological changes and the loss of traditional land management practices.





Other significant concerns include the urban-forest and urban-agriculture interfaces, which represent friction zones between different territorial functions. These transitions are often exacerbated by weak local planning frameworks or the lack of updated land-use databases, making it difficult for municipalities and stakeholders to monitor or steer land-use changes proactively.

Some Living Labs also stressed the importance of residential development patterns, particularly the proximity of new housing to key infrastructure and services, as a potential source of imbalance or marginalization. Specific examples of land-use conflict were mentioned as well, such as the conversion of farmland into shopping centres, or tensions between traditional land uses and emerging green infrastructure. While one response mentioned mining and wind energy installations as relevant issues, it was acknowledged that these topics fall outside the thematic focus of that particular Living Lab.

It is worth noting that not all participants identified land use as a current priority within their context; in some cases, the question was considered not applicable. Nevertheless, the range of responses collected reflects a shared awareness that land-use dynamics are central to many rural transitions, and that forecasting such tipping points through simulation could play a key role in anticipating impacts, informing spatial strategies, and supporting more sustainable territorial development.

Interventions Living Labs would like to test in 'what-if' scenarios

The responses gathered on the types of interventions to test through 'what-if' simulation scenarios show a broad spectrum of policy areas and strategic concerns across the Living Labs. Despite their diversity, most suggestions reflect a desire to explore the effectiveness of specific actions on rural resilience, land management, and demographic stability.

Several respondents expressed interest in testing incentive-based interventions, particularly regarding biodiversity and land preservation. One proposed simulating whether financial incentives for habitat protection are sufficient, or whether government-enforced reserves are required to achieve long-term conservation goals. Similar logic underpins proposals related to young farmers' access to land, suggesting models could test the impact of financial support, land mobilization, or policy tools aimed at facilitating generational renewal in rural territories.

Other answers focused on infrastructure-related interventions, such as improving transportation networks, welfare services, or digital connectivity. These interventions are often tied to demographic dynamics—specifically whether such improvements could make small villages more attractive or help retain and attract younger populations.

Water management and land-use adaptation also featured among the suggested interventions. Respondents were interested in testing the impact of water scarcity on crop choices and agricultural viability, particularly in relation to irrigated land expansion.

In terms of broader territorial dynamics, one response proposed examining the implications of a “status quo” scenario, characterized by uncontrolled settlement growth and increased suburban





commercial development, particularly shopping centres outside city cores, and the effects these trends might have on urban-rural balance and centrality.

Table 10. Summary of Living Lab inputs on analytical and policy relevance of the model

Category	Main themes identified	Examples and details
1. Transitions prioritized for exploration	Socioeconomic transition	This was the most frequently cited focus. It includes changes in the rural economy, employment, service provision, and demographic shifts. Many Living Labs are seeking to better understand how to respond to structural transformations in these areas.
	Environmental transition	Mentioned in some cases, particularly regarding land-use change, biodiversity, and ecological dynamics.
	Digital transition	Some Living Labs highlighted the role of broadband access and digital connectivity in shaping territorial development.
2. Hypotheses to explore through the model	Demographic dynamics	Focus on youth outmigration and the factors that may support their retention or return, such as housing availability, land-use diversification, and access to services and jobs.
	Agricultural system changes	Exploring differences between livestock types (e.g., cattle vs. sheep), irrigation use, and the implications of intensification for employment and the environment.
	Economic diversification	Interest in simulating the effects of short food supply chains, integration of agriculture and tourism, or rural business development.
	Environmental and biodiversity concerns	Some hypotheses address the effect of agricultural practices on biodiversity, especially in protected areas like Natura 2000 sites.
	Natural resources and digitalization	A few hypotheses explore how the availability of natural resources or uptake of broadband grants may influence local economic resilience.
3. Land-use conflicts and tipping points	Agriculture vs. photovoltaic infrastructure	Strong concern over the conversion of farmland into solar farms, and how to balance renewable energy production with food security and landscape preservation.
	Land abandonment and spontaneous reforestation	In some regions, unmanaged farmland is gradually reverting to forest, with ecological impacts and loss of traditional land uses.





	Urban-rural interfaces	Tensions arise at the edges of urban, agricultural, and forested areas, often worsened by outdated land-use plans or weak territorial governance.
	Residential development patterns	Worries about new housing being located far from services and infrastructure, which can contribute to marginalization or inefficient land use.
	Other specific land-use conflicts	Examples include farmland conversion into shopping centres, or clashes between traditional land uses and new green infrastructure.
4. Interventions to test through "what-if" scenarios	Conservation incentives and regulations	Simulating the impact of financial incentives for biodiversity protection versus legally enforced reserves to assess what works better in the long term.
	Youth access to land	Testing policies such as land banks, financial support, or generational renewal programs to help young farmers enter the sector.
	Infrastructure improvements	Exploring how investments in transport, social services, or digital networks might improve the attractiveness of small rural villages.
	Water management and land adaptation	Assessing how water scarcity influences crop decisions, irrigation needs, and agricultural viability under changing climate conditions.
	Uncontrolled development trends	One proposal focuses on simulating a "status quo" scenario, with continued suburbanization and the growth of shopping centres outside city centres, to evaluate the risks for territorial balance and urban-rural cohesion.

Source: own elaboration.

3. Replicability Conditions

Foresee barriers to developing a forecast model in the Living Lab

In exploring what might hinder the development of a forecast model within their Living Labs, participants were asked to select from a predefined list of common challenges, while also having the opportunity to add context-specific observations.

The most frequently selected concern was the lack of technical staff, particularly those capable of carrying out modelling tasks or managing data workflows. This points not only to a shortage of specialized personnel, but also to the broader issue of limited institutional capacity to sustain modelling activities over time.





Several respondents also expressed concerns about data access and quality. Limited availability of zoning or high-resolution satellite data was highlighted as a technical constraint, especially for models that depend on detailed land-use classifications. In the open responses, issues such as the fragmentation of data sources, inconsistent formats, and lack of reliable datasets were further emphasized.

Beyond data and staffing, a few Living Labs flagged conceptual barriers—notably the risk of oversimplifying local complexity when translating real-world dynamics into abstract models. While not a rejection of modelling, this caution reflects the need to ensure that tools remain credible and context sensitive.

Additional, specific responses also added important nuance. One Living Lab noted that forecasting models are still a new and unfamiliar territory, underscoring the need for methodological guidance and capacity-building. Another pointed to the scale of the pilot region as a potential limitation, suggesting that spatial heterogeneity could pose practical modelling challenges.

Finally, a few comments pointed to limited stakeholder engagement, often linked to a lack of prior exposure to modelling tools. This highlights the importance of building trust and understanding around simulation approaches—not just among technical staff, but within the wider community of decision-makers.

Utility of a user-friendly tool (MS Excel)

To better understand the practical needs of Living Labs, the survey included a question about the relevance of simple, user-friendly tools—such as Microsoft Excel—for use in local contexts. The aim was to evaluate whether accessible formats could serve as a bridge between technical modelling concepts and day-to-day planning or analysis activities at the local level.

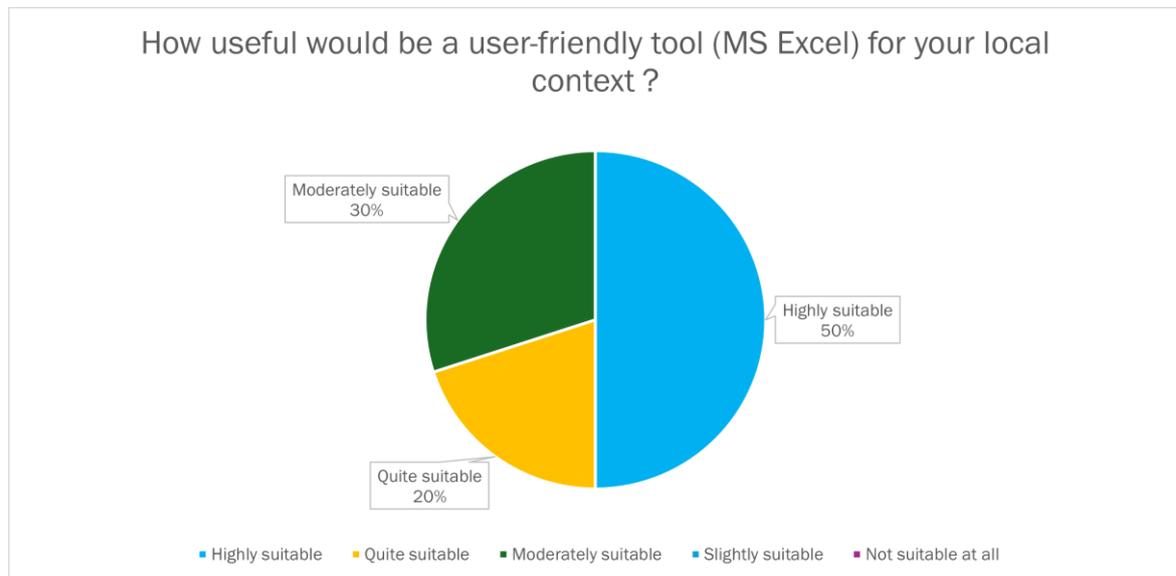
The responses show a clearly positive attitude toward such tools. Out of ten responses, four Living Labs rated an Excel-based tool as “5 – Very suitable”, expressing strong support for formats that do not require advanced software skills. Another two respondents chose 4, while three selected 3, indicating moderate interest and potential depending on use cases and available support.

Overall, the feedback suggests that ease of use and familiarity are highly valued characteristics, especially in contexts where technical resources are limited. The responses are consistent with previous findings regarding common barriers, such as limited technical staff or lack of modelling experience, reinforcing the idea that tools based on widely known platforms could be an effective entry point for local teams.





Figure 20. How useful would be a user-friendly tool (MS Excel) for your local context? (Survey: 13 answers)



Source: own elaboration.

Perceived feasibility of adapting or developing an agent-based model inspired by the RUSTIK pilot within the Living Labs

Participants were invited to reflect on the feasibility of adapting or developing an agent-based model inspired by the RUSTIK pilot, in the context of their own Living Lab. The goal was to assess not just interest, but also the perceived technical and institutional readiness to engage with a modelling framework of this nature.

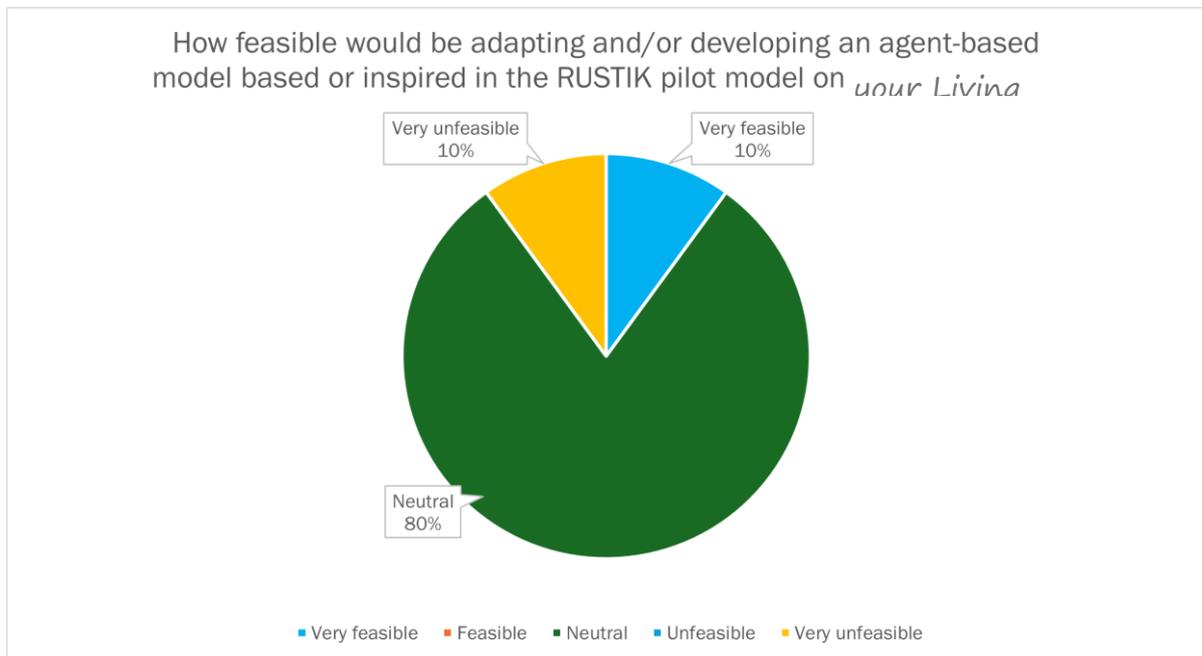
The responses reveal a moderate but cautious outlook. Most Living Labs, eight out of eleven, rated feasibility at 3, suggesting a position of uncertainty or conditional openness. This middle-ground response likely reflects a combination of factors: some familiarity with the modelling concept, interest in its potential, but also awareness of existing limitations in expertise, time, or resources.

Only one Living Lab considered the adaptation clearly feasible, while another expressed that such an endeavour would be unfeasible, possibly due to structural constraints or perceived complexity of the RUSTIK model. The overall picture, therefore, is not one of rejection, but of tentative receptiveness, depending heavily on the level of support, guidance, and adaptability of the model to local conditions.





Figure 21. How feasible would be adapting and/or developing an agent-based model based or inspired in the RUSTIK pilot model on your Living Lab? (Survey: 13 answers)



Source: own elaboration.

Necessary support in case of interest

According to the Living Labs, support is essential, and it must come in several forms.

For many, the first step is simply understanding *how* these models work. Needs for training, guidance, and basic conceptual clarity show that modelling—especially agent-based or land-use modelling, is still unfamiliar territory for most. There’s a desire to learn, but it must be matched by structured opportunities to do so.

Beyond knowledge, data remains a critical barrier. Without reliable land-use maps or clean, well-organized datasets, even the most intuitive modelling tool will struggle to take root. Several Living Labs pointed to this as a major constraint: either the data is missing, inaccessible, or simply too fragmented to be used meaningfully.

Respondents also emphasized the importance of technical implementation support—not just for strategic decisions (the “what” and “why”), but also for operational execution (the “how”). Key challenges include model initialization, data preprocessing, calibration, and result validation. This indicates that while there is motivation to participate in modelling exercises, practical execution requires targeted technical competencies that are not yet widespread among Living Lab teams.





6. Final Conclusions

- It is widely known that one of the most pressing challenges for rural regions is the limited availability and fragmentation of data. Yet rather than simply being a constraint, this initial challenge has served as a powerful catalyst for innovation in the Living Labs experimentation process. The Living Labs have shown that with the right methodologies and tools, rural territories can generate relevant, high-quality data to inform planning and policy processes, even in contexts traditionally underserved by statistical systems.
- The RUSTIK project has enabled the creation and deployment of novel methodologies for data collection, integration, and visualization. These approaches help bridge gaps between official datasets and the real needs of rural stakeholders. Examples include:
 - *Collection & visualisation.* **Participatory mapping with Maptionnaire** in Sant Miquel de Balenyà and Monmouthshire, where citizens provided georeferenced insights into quality of life and local services. In Sant Miquel, these data fed directly into the development of a localized Quality of Life Index.
 - *Integration & visualisation.* **AI-powered dashboards** in Gloucestershire, capable of real-time service gap analysis and automated reporting. This tool made data actionable for local governments and service providers, even in areas with limited technical capacity.
 - *Collection.* **Web scraping and food supply chain mapping** in Troyan and Zaječar, which created detailed inventories of food production, distribution, and consumption using semi-automated data extraction techniques and stakeholder validation.
 - *Integration.* **Decision Support Systems (DSS)** in Galicia, which integrated cadastral, biophysical, and social data to identify and prioritize ‘model settlements’ for rural regeneration and wildfire prevention.
 - *Collection.* **Survey-based entrepreneurial diagnostics** in Mazowieckie, which leveraged citizen and SME engagement to uncover untapped economic assets (such as chocolate flint) and design sustainable business ideas.
- In parallel, the **RUSTIK Viewer** is introduced as an integrated and accessible platform to bridge local and European levels of analysis. By integrating over 200 European indicators with context-specific data from the Living Labs, the Viewer enables a multi-scalar perspective on rural transitions. At the European level, it supports analysis of the five rural functions—ecosystem services, infrastructures, land-based products, production systems, and social capital—by offering thematic indicators from authoritative sources. Locally, it consolidates granular datasets generated during the experiments, allowing Living Labs to visualize and share insights in an accessible format.
- A key conclusion from the rural function analysis is that **local data significantly enriches and complements European datasets**, especially for underrepresented functions. While ecosystem services are well captured at European scale, local data proves relevant to understand social capital and institutional dynamics, which are highly contextual. For example, while European indicators reflect environmental variables such as air quality and land cover, local indicators in Osona and other Living Labs capture walkability, access to green





space, or perception of neighbourhood safety—elements crucial for wellbeing but often invisible in macro-level data.

- Lastly, the application of the **Agent-Based Land-Use Model** in Sant Miquel de Balenyà illustrates the potential of using data in modelling and scenario-building. Implemented in Excel for simplicity and accessibility, the model simulates land-use dynamics by considering initial zoning, activity attractiveness, and spatial constraints. The model has pedagogical and practical value: it allows users to test “what-if” scenarios, explore the consequences of zoning policies or economic incentives, and engage with spatial planning in a more interactive and informed way.
- Feedback from other Living Labs confirms the potential for the replication of the Agent-Based Land-Use Model, though with some caveats: many Living Labs expressed interest in using such models but noted barriers related to data availability, technical skills, and conceptual familiarity. Still, a majority consider the approach feasible and recognize the value of a user-friendly tool that can support strategic foresight in rural development.

