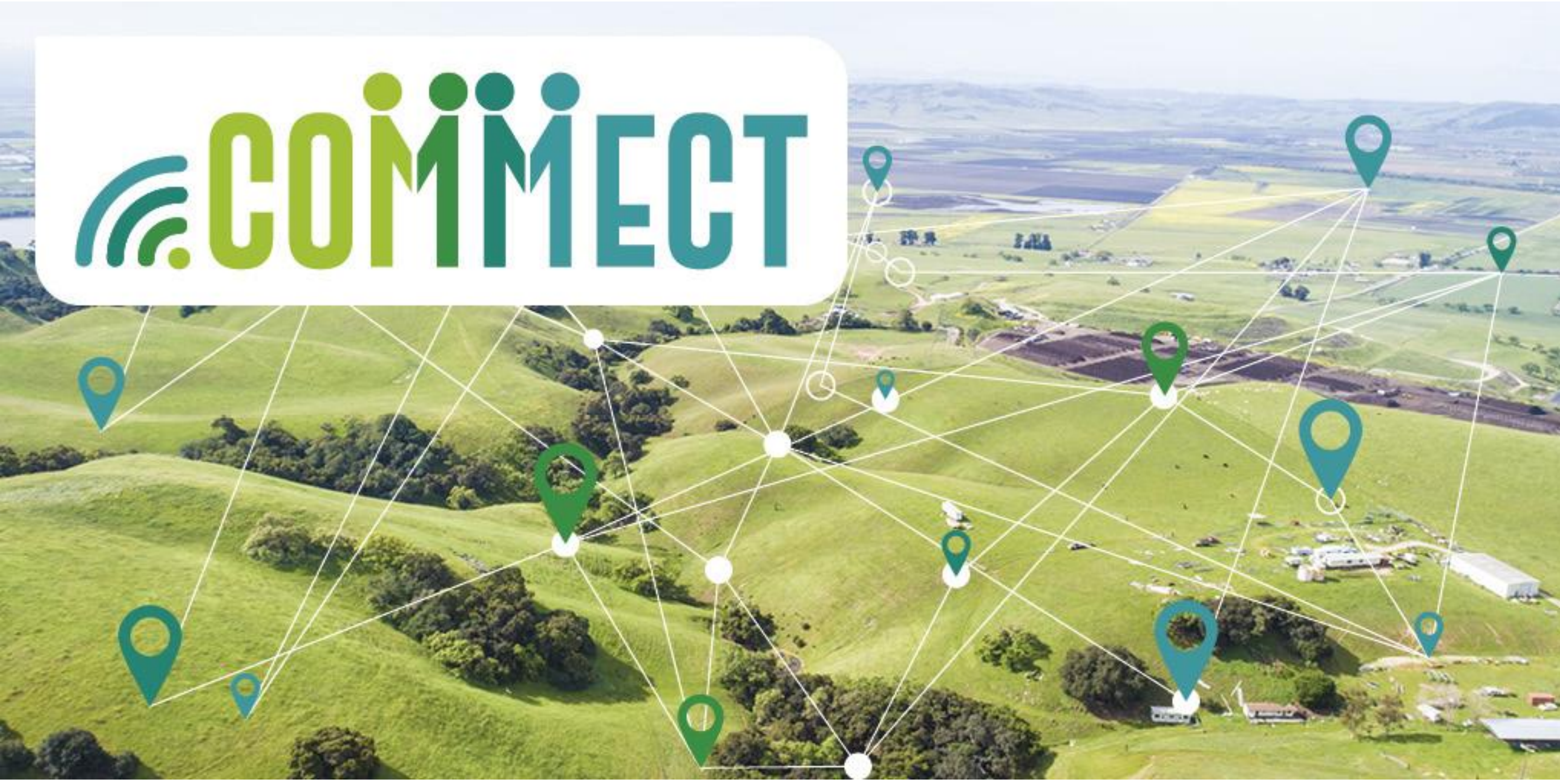
Bridging the digital divide and addressing the need of Rural Communities with Cost-effective and Environmental-Friendly Connectivity Solutions



Deliverable 3.1

Socio-Economic Impact and Environmental Sustainability Assessment

November 2023

PUBLIC

This project has received funding from the European Union’s Horizon Europe Research and Innovation Programme under grant agreement no. 101060881.

COMMECT

Bridging the digital divide and addressing the need of Rural Communities with Cost-effective and Environmental-Friendly Connectivity Solutions

Grant agreement No. 101060881

Socio-Economic Impact and Environmental Sustainability Assessment

PUBLIC

WP3 Impact Assessment Framework and Business Models

Deliverable ID	**D3.1**
Deliverable Name	**Socio-Economic Impact and Environmental Sustainability Assessment**
Lead Partner	TNOR, LIST
Contributors	TNO, INN

COMMECT Project Abstract

In recent years, the importance and need for broadband and high-speed connectivity has steadily increased. The Covid-19 pandemic has also highlighted this need and further accelerated the process towards a more connected society. However, the acceleration has largely taken place in urban communities. In Europe, 13% of people are still without broadband access, and this mainly affects the most rural and remote areas (European Commission, Directorate-General of Communications Networks, Content & Technology, 2022). Those areas are the most challenging to address since they are the least commercially attractive. COMMECT aims to **bridge the digital divide**, by providing quality, reliable, and secure access for all in rural and remote areas. The **goal of extending broadband connectivity in rural and remote areas** will be achieved by *integrating Non-Terrestrial Networks with terrestrial cellular XG networks, and low-cost Internet of Things (IoT). Artificial Intelligence, Edge and Network Automation will reduce energy consumption both at connectivity and computing level.*

A participatory approach with end-users and ICT experts working together on development challenges will be the key **for the digitalization of the sector**. To ensure the rich exchange of best-practice and technical knowledge among the actors of the agri-forest value chain, COMMECT will set up **five Living Labs across and outside Europe**, *where end-user "pains" and (connectivity) "gains" will be discussed in detail from different perspectives.*

COMMECT aims to contribute to a balanced territorial development of the EU's rural areas and their communities by making smart agriculture and forest services accessible to all. COMMECT will facilitate that by developing a **decision-making support tool** able to advise on the optimal connectivity solution, according to technical, socio-economic, and environmental considerations. This tool, incorporating collaborative business models, will be a *key enabler for jobs, business, and investment in rural areas, as well as for improving the quality of life in areas such as healthcare, education, e-government, among others.*

Document Information

Document Name	Socio-Economic Impact and Environmental Sustainability Assessment
Version No.	0.5
Due Date Annex I	30-11-2023
Report Date	03.07.2024
Number of pages	94
Lead Authors	Per J. Nesse (TNOR), Elorri Igos (LIST)
Other Authors	Simen Ulsaker (TNOR), Gorm Grønnevet (TNOR), Alya Bolowich (LIST), Federico Busio (LIST), Michaël Saidani (LIST); Virág Szijjarto (TNO), Rick Gilsing (TNO); Anne Nordli (INN); Georgios Karagiannis (HWDU)
Dissemination Level	PU

Document History

Version	Date	Description	Authors	Reviewed by
0.1	30-06-2023	Internal report	Same as above	Michael Nørremark (AU), Valtteri Manninen, Hanna Meriläinen and Anu Palomäki (SeAMK)
0.2	10-11-2023	Ready for review	Same as above	Michael Nørremark (AU), Valtteri Manninen, Hanna Meriläinen and Anu Palomäki (SeAMK)
0.3	28-11-2023	Updated version, addressing reviewers' comments	Same as above	Maria Rita Palattella (LIST)
0.4	30-11-2023	Final version	Same as above	
0.5	03-07-2024	Revision after RP1 (added Sec. 3.4, and updated the Conclusion)	Per J. Nesse (TNOR), Alya Bolowich (LIST), Anu Palomäki (SeAMK), Valtteri Manninen (SeAMK)	Rick Gilsing (TNO)

Document Approval

Version	Name	Role in the Project	Beneficiary	Date
0.3	WPs Leaders Technical Manager Innovation Manager	Members of the Executive Board	AAU, TNOR, KI, AU, INN, TNO, LIST	23-11-2023
0.4	Maria Rita Palattella	Project Coordinator	LIST	30-11-2023
0.5	Maria Rita Palattella	Project Coordinator	LIST	03-07-2024

Executive Summary

The aim of the COMMECT project is to deploy connectivity solutions to support agriculture, viticulture, forest, live-stock transport, and olive farming sectors in rural areas, whilst paying attention to how these solutions contribute towards social, economic, and environmental impact. In this deliverable, we describe the methodologies that will support the assessment of the socio-economic and environmental impacts of connectivity solutions deployed in the COMMEC Living labs. For the assessment of Socio-Economic and Environment impact we introduce protocols and portfolios of dimensions and indicators adapted to the characteristics of the different Living Labs. Several connectivity solutions are considered such as broadband connectivity, last-mile, access, and backhauling connectivity.

For the socio-economic aspects, we will apply both macro and micro level methodical approaches. The macro level is applied to get an understanding of the impact from improved roll out and coverage of fixed and mobile broadband from multiple telecom providers have on society, e.g., employment, settlement, commuting in municipalities. The advantage with the micro level approach is to get in in-depth understanding of the socio-economic impact for the Living Lab stakeholders from implementing connectivity solutions and corresponding business models in these industry domains. Here data is collection through interviews as well as surveys. The former is directed towards Living Lab leaders on the benefits for the use case stakeholders from the new connectivity solutions. The latter is directed towards other stakeholders within the value chain beyond the LL leaders. This is a larger sample online study that seeks to find significant relationships between the connectivity solutions deployed and the use case project outputs/impact. Using both quantitative and qualitative research approaches supplement each other in adding insight for the socio-economic assessment of the COMMECT LL use cases. The business model will design the exploitation of the connectivity solutions and their expected impact results and is presented in more detail in deliverable D3.3.

For the environmental analysis, the evaluation is based on the standardised life cycle assessment (LCA) methodology. The LCA can provide a comprehensive evaluation, considering the whole life cycle of a product or service and a large panel of environmental impacts. For COMMECT project, the Environmental Footprint recommendations of the EC will be followed, which includes 16 impact categories. A focus on climate change impacts (i.e., greenhouse gas emissions) will be nevertheless performed since it is a key indicator. The evaluation will include the impacts due to the deployment of the connectivity solutions (construction, operation, and disposal of ICT equipment), called first-order effects; and the enabling effects in the sector of application (e.g., reduced use of water or pesticides, transport optimization), called second-order effects. For each LL, this deliverable suggests a preliminary definition of the scope of the LCA study (including relevant use cases, system boundaries and the priority data requirements. Preliminary data for the life cycle inventory of ICT equipment and services are also described based on literature review.

All in all, this document aims at introducing the frameworks that will be used later in the COMMECT project to validate the socio-economic and environmental impact, and to design business models. The data that will be collected using these frameworks and the insight that will be derived through the following analysis, will be fed into the Decision-Making Support Tool (DST). This tool – one of the main outcomes of the project - will provide information to the end-user who wants to make an investment decision around ICT implementation, to be able to make the decision well underbuilt. All the types of impacts that will be measured or identified during the project, will be linked to the corresponding connectivity solution, and will be communicated to the end-users through the DST. The DST will be designed and developed throughout the COMMECT project.

Table of Contents

List of Figures

List of Tables

Glossary of Terms

AIOTI	Alliance for IoT and Edge Computing Innovation
dBm	decibel-milliwatts
DESI	Digital Economy and Society Index
DST	Decision-Making Support Tool
EC	European Commission
EF	Environmental Footprint
EGDC	European Green Digital Coalition
EI	Environmental Impact
HSE	Health Safety and Environment
ICT	Information and Communication Technology
IoS	Internet of Services
IoT	Internet of Things
ISO	International Organization for Standardization
ITS	Intelligent Transport Systems
ITU	International Telecommunications Union
J	joule
kg	kilogram
KPI	Key Performance Indicator
KVI	Key Value Indicator
kW	kilowatt
kWh	kilowatt hour
LC	Life Cycle
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle IImpact Assessment
LL	Living Lab
LoRa	Long Range
TAE	Total Avoided carbonEemissions
tkm	tonne.kilometer
UAV	Unmanned Aerial Vehicle
UC	Use Case
V	Volt
VR	Virtual Reality

1. Introduction

The objective of this deliverable D3.1, output of WP3 Impact Assessment Framework and Business Models, is to describe the methodology that will be used to assess the socio-economic and environmental impact generated by connectivity solutions, designed and deployed by COMMECT. With these impact assessment methodologies in place, we are able to better understand the extent of the benefits for firms and end users from the adoption of the connectivity solutions in the Living labs in the rural areas, as well as how far they can contribute to climate mitigation and other sustainability targets. This deliverable will function as a basis for the socio-economic and environmental impact validation in the different LL in WP 5 (Validation of COMMECT solutions). Moreover, the output of the methodologies will also feed into the design and implementation of the decision-making support tool (DST) in deliverable D3.3 (Decision-making Support Tool version 1). The LL domains involved are the Digitalization of Viticulture in Luxembourg, Connected Forestry in Norway, Connected Livestock Transport in Denmark, Smart Olive Farming in Turkey and Sustainable Agriculture and Preservation of Natural Environment in Serbia. The type and scope of connectivity solutions differs between the COMMECT living labs such as last mine, backhauling, combined terrestrial and satellite. These are described more in detail in deliverable D2.2.

The document first introduces the *socio-economic assessment* methodology, which combines two approaches, namely the broader macro level impact, and the narrower micro level impact. The former approach covers the impact from increased connectivity on country/regional level, while the latter study the impact from enhanced connectivity solutions on use case level. Both approaches are piloted in the LL2 Norway initially and thereafter introduced in the other four Living Labs to examine how these can be used. Quantitative research methods are used at the country/regional level (macro perspective), while qualitative research methods are applied at the use case level (micro perspective).

Next, the *environmental assessment* methodology is introduced. First the LCA methodology is explained in general, and then a translation is made towards the project context, explaining how the methodology will be applied in the five Living Labs.

Finally, it is explained how the outcomes of the previously described assessments will be used in the DST tool, and what the next steps to apply the proposed methodologies in the project will be.

2. Socio-Economic Impact Assessment Methodology

2.1. Overview

2.1.1. Socio-Economic Impact Assessment

Socio-Economic Impact Assessment (SEIA) refers to identification and evaluation of the degree of economical and societal contribution from a research and development program or project on the stakeholders influenced by the project output. This can be businesses, users, and other beneficiaries directly or indirectly. Socio - economic impact assessment analysis is often performed alongside the analysis of the technology developed and of a given project. In this deliverable, we will focus on including impact dimensions such the usability, economic trade-offs for stakeholders as well as effects for the society/community from enhanced connectivity solutions in the five countries involved in the COMMECT project.

We will apply two different levels (macro and micro) of methodical approach with respect to data collection for the socio-economic framework section. In the following an overall description and illustration of the SEIA process going forward is described, see Figure 1 below.

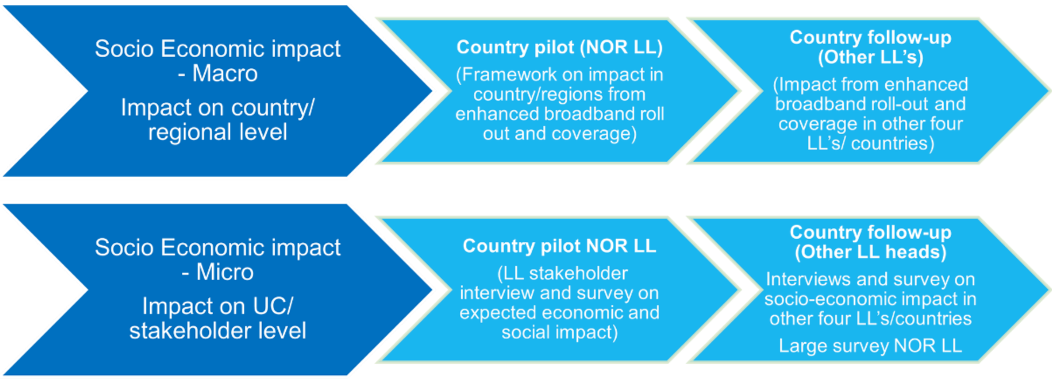


Figure 1. Methodological approach for socio-economic impact assessment framework

For the **Macro level** the objective is the following:

The aim here is to understand the impact from enhanced connectivity (e.g., high speed fixed and mobile broadband) on socio-economic outcomes at the regional/country level. The method outlined combines data on broadband connectivity and socio-economic outcomes at a regional/country level and investigates whether improvements in connectivity over time is associated with changes in the socio-economic outcomes such as employment and ability to work remotely and reduce amount of commuting between municipalities.

To illustrate the macro level method, we piloted the study by using regional data from Norway. We used yearly connectivity data from year 2000 until today reported by the Norwegian communication authority (NKOM) at the municipality level. This data described the roll out and coverage of fixed broadband from multiple telecom providers in Norway. The regional broadband data covers all of the Norwegian country, hence goes beyond the Connected Forestry LL region itself. In addition, we add data from Statistics Norway on demographical data in the regions studied, related to employment, settlement, commuting etc. during the same period to analyse possible consistencies. An identical approach was then applied for the other four COMMECT LL countries. Some challenges were experiences with acquiring data on broadband roll out and socio-economic outcomes from Turkey and Serbia, disabling us to perform identical analysis across all five countries. However, data were collected from the latter countries, although not directly comparable, hence a macro level analysis is conducted in each of the four LL's.

For the **Micro level** the objectives and methods are two-fold:

The first objective is to understand the socio-economic impact from implementation of enhanced connectivity solutions in the Living Labs in each of the five countries. The method we use here is interviews of the leaders of the Living Labs asking them about which connectivity solutions they plan to apply to solve the challenges in the different use cases they have identified. Furthermore, we ask the LL leaders to assess the expected benefits and potential challenges/trade-offs the enhanced connectivity solutions may have for their company and other value chain stakeholders including the municipalities.

The second objective is to provide insight from LL use case end users on their pre-conditions for performing innovation of processes and products/services. The method we use here is distribution of questionnaires online to the value chain stakeholders in the five LL's. This includes independent contractors and companies involved in the value chain activities/steps. From the companies' this involves turnover figures, type and degree of innovation/patents, external partner cooperation/openness, degree of agile approach to innovation as well as information about the company/respondent (management education, number, and type of (female/male) employees etc). Questions on the expected impact (ref. first objective) will also be included in the survey in order to reach a larger set of respondents. A survey questionnaire was piloted for the Norwegian LL and will be followed-up in the other LL's.

As pointed out, this section describes the methodology for assessing the societal and economic impact from implementation of an enhanced connectivity solutions in the five COMMECT Living Labs. This methodology makes use of both qualitative and quantitative research techniques, hence mitigates the limitations of using single techniques for impact assessment of EU funded research projects [1] [2].

In the following chapter we review the relevant literature and present the techniques used within the socio-economic impact assessment methodology. This section also describes an agile process that describes the main steps of design, development, and trials of the different connectivity solutions in the five LLs. These solutions are designed based on users' needs and requirements in the different use cases described in D1.1 (Report on end-user needs and relevant use cases). The assessment of the environmental impact from the connectivity solutions introduced is presented in a separate section of this deliverable.

2.2. State-of-the-art literature review

This section includes an overview of state-of-the-art literature related to the major topics handled in this report. The review is based on research findings in scientific articles as well as comparable EU funded research projects. The selection of the former is done using online university databases such as ntnu.oria.no focusing on peer review articles published the last decade. The selection of the latter refers to findings on socio-economic impact methodologies/ frameworks from ongoing research projects within the Horizon Europe program. We start by introducing an agile process for research and innovation projects that target to develop enhanced connectivity solutions. There after we introduce theories and previous findings related to the methodology we apply for macro and micro level analysis of the business and societal impacts from the solutions developed.

2.2.1. Agile development approach

An agile methodology describes the development of the use cases in the different LL's. It helps the LL leaders to handle the risk and uncertainty better. In the Figure 2 below a four-stage iterative development and innovation process in real life environments [3]:

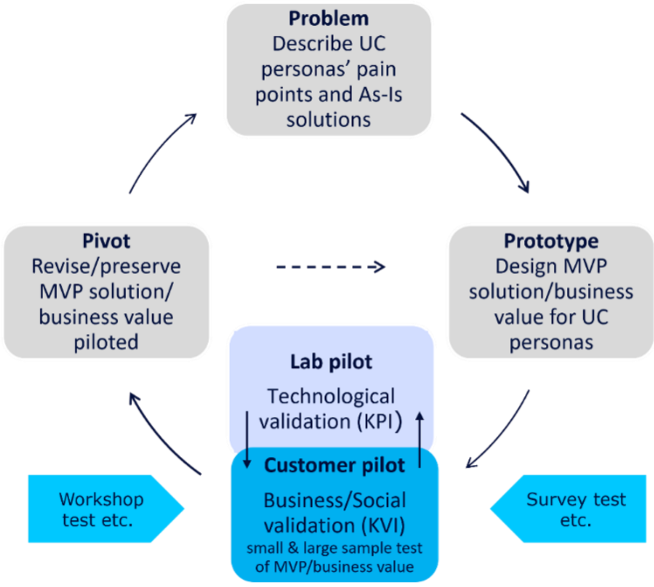


Figure 2. Agile process for research and innovation projects

1. Problems: Map needs and problems for value chain stakeholders in the LLs. Collecting feedback and data through workshops, interviews, surveys etc.
2. Prototype: Define requirements and design prototypes or minimum viable product's (MVP's) of possible solutions mitigating the problems identified. Specify supporting test infrastructure set-ups.
3. Pilot: Tests prototypes/MVPs designed to mitigate needs/problems identified. Lab (or field) test pilots using connectivity test infrastructure for doing measurements of performance-based indicators, key performance indicators (KPIs). Also includes customer measurements of value-based indicators, key value indicators (KVIs)
4. Pivot: Evaluate measurements/results from MVP/prototype tests with respect to performance, society, economy, and environment. Results are input to revisions of solutions and test set-ups.

Design thinking and lean start/agile way of work are state of the art bottom-up innovation process principles and methodologies applied in industries and businesses today that helps explore and tackle research-based problems that often are ill-defined or unknown [4]. According to Cooper [5] and Ries [6] co-creation and development with users and customers avoids doing unnecessary redesign due to lack of feedback on prototypes/MPVs from stakeholders/actor groups external to the innovation project, hence gets the desired product to customers' hands faster.

A use case describes the ways that stakeholders want to use a system (technology, process, device) to perform a task or activity and hence reach an overall goal [7]. The latter involves the validation of the perceived impact for these stakeholders. In the context of the COMMECT Connected Forest living Lab, we see a use case as a concrete situation or event, where one or alternative connectivity solutions may be applied, and where identified persons hold stakes in the situation/event [4]. In COMMECT, the use cases are built up through a bottom-up approach using the agile development process steps with early MVPs of the ICT solution presented for feedback and revisions by the stakeholders.

A study of small and medium sized (SMEs) and multinational companies (MNC's) in the EU funded 5G SOLUTIONS research and innovation project shows that collaboration is valuable for accessing key competencies and vertical industry ecosystem [8]. SMEs benefit from technology-related activities and access to decision makers in MNCs and MNC's benefit from business-related activities by advertising technology to clients and suppliers. The suggestions are that the assessment of the client's needs is needed in parallel with trialing of technology and service concepts, as well as the dissemination of the results from the collaborative R&I activities.

Societal effects from broadband connectivity

The following literature review covers some of the most important contributions on research findings about impact from increased fixed or mobile broadband connectivity on a country/regional level. Much of the existing literature focuses on developing economies but there are also several studies in the European context. Below we give a brief and non-exhaustive review of this literature.

Using the gradual roll-out of broadband internet in Norway between 2000 and 2008, Akerman et al. [9] estimates the effect of (fixed) broadband connectivity on labor productivity and wages in Norway. They find that broadband internet improves productivity of skilled workers but reduces productivity for unskilled workers. Productivity here refers to production per input factor, here workforce, i.e., per worker. DeStefano et al. [10] study the effect of the arrival of ADSL broadband in the UK on firms and find that access to broadband led to increases in firm size but not in productivity. Hasbi [11] finds that municipalities with very high-speed broadband networks in France tend to be more attractive for companies, with a positive effect on establishment creation within the tertiary sector and the construction sector. Canzian et al. [12] analyze the impact of advanced (up to 20 Mbps download, up to 1 Mbps upload) (fixed) broadband accessibility on firm performance in rural areas in the Province of Trento in Italy between 2011 and 2014. They find that broadband connectivity is associated with increases in firms' revenue and total factor productivity but not with significant changes in personnel cost or employment. Briglauer et al. [13] assess the economic benefits of high-speed (fixed) broadband within and across neighboring counties in Germany from 2010 to 2015. They find that an increase in average broadband speed has a significantly positive effect on regional GDP (Gross Domestic Product) in the average German county.

There are findings from developing economies that refer to socio-economic impact from increased mobile connectivity. Aker [14] finds that the rolling out of mobile phone service in Niger between 2000 and 2006 lead to a more efficient agricultural markets, while Jensen [15] shows that markets become more efficient (less price dispersion and waste) when fishermen and wholesalers have access to mobile phones (during 1996 to 2014). Beuerman et al. [16] find that mobile phone coverage (during 2004 to 2009) led to increases in consumption levels and decreases in poverty rates in rural Peru. Flückiger and Ludwig [17] find that infant mortality risk drops substantially in sub-Saharan Africa as mobile phone coverage (2G) expands and suggests that improved health knowledge is a likely explanation of their findings.

Qualitative Comparative Analysis (QCA)

For in-depth analysis of data gathered from small or large sample interviews, qualitative methods like Qualitative Comparative Analysis (QCA) provides valuable insights. The QCA method examines the causal relationship between multiple conditions in combination and an outcome of interest [18] [19]. It is a theoretic approach [19] that involves assigning cases as members or non-members of sets and evaluating different combinations of conditions (set memberships) to identify necessary and sufficient conditions for the outcome. While QCA is often associated with intensive qualitative engagement and the use of in-depth case knowledge (a case-oriented approach) it can also use large data samples with less weight on qualitative insights [20]. Conditions are necessary when each time the outcome occurs, the condition is also present [21] and conditions are sufficient when each time the condition is present, the outcome is also present. A truth table contains all sufficient combinations of conditions for the outcome's occurrence and the Quine-McCluskey algorithm is used to analyse, i.e., logically minimize the various sufficient combinations in the truth table to a minimum formula of configurations (combinations of conditions) that lead to the outcome [22] [19]. One of the main benefits of using QCA is that it allows for comparisons across cases and configurations. Rather than simply examining the relationship between one or two conditions and an outcome, QCA allows for the examination of multiple conditions and their combinations, and how these combinations can lead to the same outcome in different ways [19].

Overall, QCA is a flexible and powerful method for examining complex relationships between conditions and outcomes. Identifying necessary and sufficient conditions and multiple causal recipes can provide valuable insights into how different conditions interact and influence outcomes of interest. The QCA method will be further elaborated with an example in the micro level methodology chapter of this report.

Impact assessment methodologies from different EU funded research and innovation projects

A general perception regarding assessment of impact in R&D projects in the EU context is that single techniques (collection of statistics, feedback from collaborators, case studies, financial methods, multicriteria, input-put put analysis are not able themselves to fully satisfy the need for a comprehensive overview within the same methodology/analytical framework. With this backdrop, the SEQUOIA project defined a methodology based on the combined use of different techniques in order to overcome these limits. The SEQUOIA methodology refers to the self-assessment of the socio-economic impact of Software-as-a-Service (SaaS) and Internet of Services (IoS) in the context of EU-funded research projects (FP7). It is structured in four main steps [1]:

1. Mapping the areas of impact: identify stakeholders impacted by the outputs of the project.
2. Baseline identification: collect information regarding ex ante scenario, i.e., the situation before the project started.
3. Ex post scenario description: describing, through use of different indicators, the situation after project completion and exploitation.
4. Final assessment analysis: Collect process data from previous steps, using different techniques, for performance evaluation and benchmark.

Table 1 below describes economic impact indicators (ref. step #3), i.e., project contribution to the competitive performance for consortium and users of the research outputs) and social impact indicators i.e., project contribution at any level of social interaction, to users or direct/indirect beneficiaries) In relation to final economic impact assessment (ref. step #4) quantitative cost-benefit/return on Investment (ROI) analysis techniques where used, while in relation to the social impact assessment qualitative multi-criteria analysis (MCA) techniques of non-monetizable impacts were used.

Table 1. Economic and Social impacts indicators included in the SEQUOIA methodology.

Financial (Economical)	Technological (Economical)	Environmental (Economical)
Investment cost (Total project cost)	Operational Efficiency	Saving energy consumption
Maintenance cost of IoS/SaaS	Accessibility	Savings on storage related cost
Labor cost implementing IoS/SaaS	Effectiveness	Travel cost

Product of IoS/SaaS sales	Satisfaction	Technological waste production
Royalties	Security	Consuming saving/ selling off paper

Employment (Social)	**Knowledge production (Social)**	**Social Capital (Social)**
Impact on general employment	Scientific Impact	Social capital increment for project participants
Impact on working routines	Knowledge sharing	
Increment in skilled personnel employment	Support of ICT use for all and demographic participation	Social capital for users and beneficiaries

Vidueira et. al [2] assessed the socio-economic impact in European rural development programs (RDPs) from the period 2007 through 2013. They point out that there is a lack of mixed method approaches since qualitative methods are used in substitution of quantitative ones and that qualitative approaches on their own have been found as not suitable for ex ante impact assessment. The recommend that, due to time and budgetary constraints, mixed methods should mainly be applied on the most relevant impacts for the program success. Ex ante evaluation here refers here to "analysis of program's strategy, initial situation, main objectives and their quantifiable goals". This analysis makes it possible to accomplish a midterm and ex post evaluation of the program that demonstrates its success or failure. Within this context the a list of 7 socio-economic and environmental impact indicators are requested to be applied and quantified by Common Monitoring and Evaluation Framework (CMEF) during the ex-ante evaluation (1) economic growth; (2) employment creation; (3) labor productivity; (4) reversing biodiversity decline; (5) maintenance of high nature value farming and forestry areas; (6) improvement in water quality; and (7) contribution to combating climate change. Other specific impact indicators could be added if needed for a complete identification of program's expected impacts.

A comparison of other ongoing EU funded research and innovation projects that apply methodologies for assessment of socio-economic impact is a similar grouping of the impact indicators as indicated by Passani et. al. [1]. In the following groups/indicators applied in four other EU supported projects are presented.

QuantiFarm is a Horizon Europe research and innovation action (RIA) project. Their objective is to assess the impact of digital technology solutions in agriculture in real-life situations. This project operates with an assessment framework that covers three themes or categories of KVI's, also referred to sustainability domains: social, economic, and environmental [23]. In Table 2 below these three domains/dimensions is again grouped with multiple indicators or parameters

Table 2. Three main impact assessment dimensions and indictors for Quantifarm project

Social domain/impact	**Economic domain/impact**	**Environmental domain/impact**
Internal Social sustainability • Education (training hours and working time)	Profitability • Net Farm Income, Production costs, Gross Profit margin, Net profit margin, Net value	Atmosphere • Greenhouse gases and air quality Water

• Working conditions (rate of occupational injuries, physical and mental wellbeing etc.) • Food safety (contamination of heavy metals etc.)	added, sales value added, and revenue. Productivity • Land, labor, milk, bees and oyster productivity	• Water quality and withdrawal Land • Soil biological and chemical properties
External Social sustainability • Local community (contribution to economy and employment) • Involvement and participation (stakeholder meetings and farmers social involvement) • Transparency and visibility (sustainability certification and information on labels	Efficiency • Feed conversion ratio • Rate of time (to complete an activity) • Precision and accuracy Food quality • "Intrinsic" product quality (degree of acceptability of product to consume	Biodiversity • Bio-diversity conservation Waste • Generated waste Energy and Input • Energy use, renewable energy. nutrients and pesticides use Animal welfare • Animal health and welfare

Table 2 shows that the economic domain cover four different subcategories – profitability, productivity, efficiency, and food quality. The societal domain constitutes of two major sub domains – the internal impact for the unit of analysis (farmer) and the impact for external community and stakeholders. The environmental impact covers seven categories, including land/water, atmosphere as well as animals. Several of the indicators are relevant for the COMMECT, but neither of them is particularly designed for the forest sector is displayed. The Quantifarm's research methodology is to assess and demonstrate costs, benefits, and environmental impact via 30 test cases. A set of farms will have digital technological implemented (DAT) and these farms will be compared to farms that are not using these digital solutions.

The FIDAL project focus on field trials beyond 5G in two vertical industries: multi-media and PPDR (Public Protection and Disaster Relief). The aim is to evaluate the solutions by the stakeholders in all trial phases as well as for the open call's trials with suggested solutions from the external partners. The projects methodology apply three groups of dimensions and attached indicators for assessment of the socio-economic assessment of the use case solutions to be tested in the different field trials, see Table 3 below. These indicators help validate the Business and Social performance impact of their seven use cases and are applied alongside the technological KPI's validating the technical performance of the solutions.

Table 3. Groups of socio-economic assessment dimension per use case in the FIDAL project

Democracy	**Ecosystem**	**Innovation**
Privacy: • The appropriate use of data relating an individual to a context. Trust:	Sustainability: • Maintaining activity at a consistent level over time, with minimal adverse impact. Business value:	Safety: • Protection of humans, to prevent harm. Security: • Protection of data and socio-technical systems in a way

• FIDAL deemed trustworthy, stakeholders make themselves vulnerable. Digital inclusion: • Designing technologies that serve the historically under-served. Fairness: • Judgements that adapt general regulation to accommodate situational factors.	• Relating to the commercial benefit introduced. Economic growth: • Building a competitive and resilient economy, investing in skills, education, and digital transformation. Open collaboration: • Using methods based on collaboration and knowledge sharing. New value chain: Novel members or dynamics to existing supply chains.	that prevents negative impact. Regulation: • Consideration of legally binding rules that an information system must follow. Responsibility: • Being accountable for (and having control over) system behaviours. Energy consumption: • A measure of the power used in running components.

According to Table 3, we find societal, economic and environmental impact dimensions distributed throughout the three groups of dimensions (Democracy, Ecosystem and Innovation). The FIDAL project is not directed towards the forest and agriculture project per se, but several of the impact dimensions are generic and especially dimensions related to the PPDR vertical is relevant to adopt, since it is found partly in some of the COMMECT LLs.

The XGain project is, similar to the COMMECT project, a Horizon Europe collaborative project on digital transformation in agriculture and rural areas through cost-effective and environmentally friendly solutions ecosystem of technologies. Moreover, they assess the socio economic and environmental effects related to the technologies and will develop innovative business models in accordance with the performed assessments. XGain plan for use an online based tool ADOPT developed in collaboration with CSIRO, traditionally used to assess the adoption and diffusion of innovations in the agricultural sector. This tool builds on the adoption and diffusion theory by Rogers [24] and with a focus on the following base variables [25]:

- Relative advantage: the degree to which an innovation is sees as better than the idea, product, or program it replaces.
- Compatibility: How consistent the innovation is with the values, experiences, and need of potential adopters.
- Complexity: How difficult the innovation is to understand and/or to use
- Trialability: The extent to which the innovation can be tested or experimented with before a commitment to adopt is made.
- Observability: The extent to which the innovation provides tangible results

With respect to the relative advantage of the innovation for the population, XGain apply multiple dimensions, such as profit orientation, environmental orientation, risk orientation, enterprise scale and management horizon. Relative advantage of the innovation is divided between profit (during the years used, in the future and the timing for the benefits to be realized) and environmental advantage (including timing for benefits to be realized). The cost issue is also included (up-front cost of innovation), as well as risk and ease & convenience.

The 6G SNS (Smart Networks and Services) operates with a fixed set of 12 different KVIs when measuring the impact of 6G use cases. The six use cases they operate with are I) Personal health monitoring and actuation, II) Smart city with urban mobility, III) Sustainable food production, IV) Emergency response & warning systems, V) Assistance from twinned collaborative robots, and VI) Living and working anywhere. All of them are societal and in relation to one or more of the UN nineteen sustainable development goals. They operate with the following main classes of Societal-Economic KVI's: Environmental sustainability, Societal sustainability, Economic sustainability, Democracy, Cultural connection, Knowledge, Privacy and Confidentiality, Simplified life, Digital Inclusion, Personal freedom, Personal health and finally Trust. The 6G SNS white paper suggests a stepwise methodology for analysis of KVIs:

- First identify societal pain points for use case stakeholders
- Then identify relevant, positively affected key value (KVs) through 6G enabled solution.
- Finally scale of the effect that is identified, i.e., key value indicators KVI's and finally determine the enablers and blockers of usage - the KV enablers.

Two 6G use cases with KV and KVI's with relevance for COMMECT UCs are described in Table 4 and 5 below.

6G SNS also relate the evaluating KVI's related to when it occurs in the technological development process. Early in the technology development (lower technology readiness), the subjective evaluation could happen through trials, experiments, interviews etc. Objective evaluation occurs by subject matter experts. For later in the technology development/ readiness, subjective evaluation happens through questionnaires, interviews, focus groups and objective evaluation through measurements on deployed networks.

Table 4. Emergency response and warning systems 6G use case, relative KVI's and enablers

KV examples	**KVI examples**	**KV enabler examples**
Societal sustainability	Reduced emergency response times; Increased operational efficiency of interventions in remote areas	Flexible network fabric with dynamic network and service orchestration and automation; Mobile ad-hoc networking; TN/NTN convergence
Environmental sustainability	Increased area of protected and surveyed natural habitats and climate preserves	Energy-efficient monitoring sensors; Flexible analytics services and network automation; Mobile ad-hoc networking; TN/NTN convergence
Personal health and protection from harm	Increased operational efficiency for saving lives in emergencies; Reduced injuries in PPDR missions	Joint communication and sensing; Safe and easy to use XR devices; Network and service automation for low-latency analytics
Trust	Reported confidence in advanced digital devices, systems, and services in critical missions	Rugged and robust devices; Secure and trustworthy AI; System E2E privacy and security

Table 5. The "Living and working everywhere" 6G use case, relative KVI's and enablers

KV examples	**KVI examples**	**KV enabler examples**
Societal sustainability	Travelling / commuting time reduction; Access to job market; Life opportunities in rural areas	Ubiquitous coverage for basic MBB; Low-cost connectivity
Economical sustainability and innovation	Cost-efficiency of living and working in rural areas; Number of activities that can be performed anywhere	Operational cost efficiency; Low-cost scalability and expandability
Cultural connection	Access to cultural products (#products / product types); Access to cultural events (#events / product	Extended service coverage with sufficient QoS – especially for XR applications; XR reality services

	types); Number of cultural domains impacted	
Digital inclusion	Access to internet in communities and areas	Joint communication and sensing; Safe and easy to use XR devices; Network and service automation for low-latency analytics
Knowledge	Access to quality education (at all levels, esp. higher); Access to digital libraries; Access to and interaction with knowledge groups	Ubiquitous coverage for basic MBB
Democracy	Access to / active participation in administrative and political functions	Merged reality and multimodal communication services

Reviewing the research findings on assessment of socio-economic impact revels an array of different dimensions and indicators to be applied. These are listed below (non-exhaustive):

Economic impact:

- Profitability: e.g., investment costs, net profit margin, sales and revenues, royalties
- Productivity: e.g., production per input factor, e.g land, labor etc.
- Efficiency: e.g., rate of time (to complete an activity, precision and accuracy
- Quality: e.g., product quality (degree of acceptability of product to consume

Social impact:

- Knowledge and education: e.g., access to quality education, training hours and working time.
- Working conditions: e.g., rate of occupational injuries, physical and mental wellbeing
- Collaboration and involvement: e.g., community/stakeholder meetings, open innovation,
- Social sustainability and Innovation: e.g., travelling / commuting time reduction; Access to job market; life opportunities in rural areas, cost-efficiency of living and working in rural areas.
- Accessibility and democracy, e.g., access to internet in communities, participation in administrative and political functions, access to cultural products
- Transparency and visibility (sustainability certification and information on labels
- Privacy, safety, security, e.g., protection of humans, data related to individuals, and socio-technical systems.
- Regulation, responsibility, trust: e.g., legally binding rules, accountability for systems behaviour, confidence in advanced digital devices, systems, and services in critical missions.

2.3. Suggested methodologies for socio-economic impact assessment

From the literature review in the previous chapter, we find methodologies and common set of indicators used for assessment of EU funded socio-economic impacts of research and development project outcomes. These dimensions and indicators and included in methodology suggested to be used for the COMMECT project. Initially we present the methodology and country level findings from the macro level analysis. Thereafter we present the methodology for the micro level analysis. The major findings from micro level analysis in the different LL's will be presented in deliverable D5.3 (Report on the Socio-Economic and Environmental Impact in the Living Labs version 1).

2.3.1. **Methodology at macro level**

This section lays out the state-of-the-art methodology for assessing socio-economic impact of mobile and fixed connectivity at the macro level. The potential for application of this method in the Living Labs-countries is discussed and key data sources are identified.

Dubbed “the greatest invention of our time” [26], fast internet has transformed our societies and economies in numerous and fundamental ways. A substantial research literature has been devoted to estimating the effect of broadband internet (fixed and mobile) on a range of socio-economic outcomes including employment, productivity, and market efficiency. A key challenge to identifying the effect of better connectivity is that broadband coverage is not randomly distributed. Regions differ in outcomes such as productivity and employment for many reasons that have nothing to do with connectivity. Simply comparing outcomes – say firm productivity or wages – in units with different levels of connectivity will therefore give misleading results. To credibly estimate the effect of improved connectivity, researchers therefore tend to exploit the fact that broadband connectivity is rolled progressively in a given country, with some regions getting access earlier than others. This makes it possible to compare *changes* in the outcome in question for units that get access to broadband connectivity (these units are called *treated* units) to changes in the outcome for units that do not get access at the same point in time (these units are called *control* units). The underlying assumption is that the treatment group would have developed in parallel to the control group in absence of the treatment. This means that we can then attribute increases or decreases in the *differences* between the treated and control units can be attributed to the treated units getting access to broadband internet. The idea is illustrated in figure 3 below (the y-axis refers to outcome, not specified).

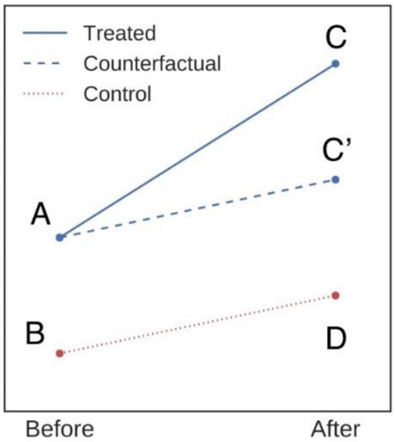


Figure 3. Illustration of the common trend assumption. If we assume that the treated units would have evolved in parallel to the control units, had it not been for the treatment, we can estimate the effect of the treatment as C-C' = (C-D) - (A-B)

The canonical way of estimating the effect of broadband connectivity on socio-economic outcomes is to estimate an equation of the following form using ordinary least squares (OLS):

$$y_{it} = \alpha_i + \lambda_t + \beta D_{it} + \varepsilon_{it}$$

In this equation, y_{it} is the outcome of interest, *e.g*., the employment rate, while D_{it} is the variable measuring broadband connectivity. D_{it} could be a binary variable indicating whether unit *i* has access to broadband internet at time *t*, or it could be a continuous variable measuring the degree of connectivity (e.g., the share of households having access to broadband in a given region in time *t*). α_i are fixed effects (dummy variables 1or 0) at the unit level, allowing each unit a different intercept. This allows the treatment and control units to have different average levels of the outcome of interest. λ_t are fixed effects (dummy variables) at the time level, incorporating shocks and developments that affect both the treatment and the control units. The inclusion of the fixed effects allows us to separate out general development in the outcome that is not related to changes in connectivity and that affects both treatment units and control units the same (through the time fixed effects) and inherent differences in the level of the outcome between the treatment and control units (through the unit time effects). Because the model includes both unit level and time fixed effects, this model is often called a two-way fixed effects model.

2.3.2. **Methodology at micro level**

This section lays out the framework for assessing socio-economic impact from mobile and fixed enhanced connectivity solutions at the micro level, represented in the five COMMECT Living Labs. The data collection methods applied at the micro level are both in-depth interviews as well as surveys.

The main goal is to develop an understanding of the impact from new connectivity solutions on various parts of rural life and the causal effects on social-economic outcomes. The survey will address how culture, social, and work practice elements play a role in terms of utilizing the connectivity solutions best possible in the Living Labs. Among some, cultural elements concern the role of trust between local and national actors between actors. Social elements relate to which collaboration partners are important and where they are geographically situated (open-mindedness and bridging/bonding social capital). Moreover, work practice elements focus on the role of innovation, design thinking techniques, and co-creation with users. In the following, we present how the survey and the measures used in the survey are developed and conducted. Lastly, we introduce the plans for using the QCA analysis method, after which some reflections on the reliability and validity of the planned study are presented. Findings from initial interviews with Living Lab leaders on the expected socio-economic impact is presented in the end.

Survey-questionnaire

A survey questionnaire (see Appendix 1) has been developed with a focus on the micro level, i.e., large sample study of stakeholders in the COMMECT LLs. These stakeholders relate to the use cases and value chain in the five Living Labs and are small and large firms, sole proprietary businesses such as farmers and forest owners in addition to end users. It is the manager in the businesses who are asked to answer the questionnaire (In larger firms, the top manager or alternatively an innovation/R&D or project manager are asked to reply to the questionnaire). The survey is built-up of five sections:

- Section 1 asks about company information such as size (number and type (female/male employees), education level of employees/management, and information on where they recruit their employees. The objective is to investigate which preconditions that need to be in place in the companies for enabling the utilization of new technologies.

- Section 2 asks about the company’s innovation activities, i.e., which types of innovation they have implemented and which partners they have collaborated with in their innovation activity. The measures used in the section are identic with the measurements in the Community Innovation Survey and are based on the latest version of the Oslo Manual [27]. Also, the indicators that capture collaboration with external partners are from the COS 2018. Implementation of new connectivity solutions demands companies to change how they work, i.e., they must have the competencies to innovate and be willing to innovate in terms of utilizing new connectivity solutions. Thus, how innovative oriented the companies in the COMMECT project are may lay a basis for succeeding with new connectivity solutions, which makes innovation interesting to investigate in the survey. Also, reaching a high level of positive effects with the new technology solutions may demand competencies in specific types of innovation, something that the measures allow to investigate).

- Section 3 asks about information about company turnover, customers location, company spending on R&D and innovation, and patenting. The section also includes questions on trust and attitude towards adoption of new technologies. All these concepts may also play a role for companies and how they solve implementation of new technologies.

- Section 4 proposes a set of questions about approaches to development of products and service solutions. These questions link specifically to the literature on design thinking techniques. Design thinking, a design-based approach to solving human problems, is increasingly adopted by firms to develop innovations [28].

- Section 5 seeks to capture whether respondents expect improvements or benefits from introducing improved connectivity solutions in company processes/tasks that will be trialled/piloted in the Living Lab pilots. These measures include several questions that link to the degree of impact related to economic, social as well as environmental benefits.

Before launching the survey questionnaire to the COMMECT stakeholders, it will be pretested. This pre-test is already performed on the small group (4-6 persons) related to the Connected Forestry LL in Norway. They filled in the questionnaire and reported back on potential challenges and inconsistencies. Revisions will be made, based on their feedback. This will also increase the reliability of the data/responses from the following respondents in the COMMECT Living Labs. Similar pretests will be executed in the other LLs, as soon as the questionnaire is translated to the given language for each LL.

Sample of surveys
The survey is constructed to target companies and organisations that plan for or have already implemented new enhanced connectivity solutions in direct or indirect relation to the Living Labs. Both small (self-employed) and larger companies will be asked, together with public organisations, but with the common goal to implement and gain effects from new connectivity solutions. Moreover, the target population is restricted to the industries that are represented in the Living Labs and primary in the rural areas. Due to uncertainties related to how many stakeholders in the living labs that will join in testing new technology, the sample will be expanded to stakeholders within the value chain related to the Living Lab use cases.

If not possible to carry out expanded surveys in all five Living Lab countries, an alternative could be to only run such a survey in a selected country such as Norway. This means running the survey on companies and managers who are responsible for work tasks and organization of the work in various aspects of forestry value chain. It was identified two relevant ways of how such sampling could be done:

- "The Machine Contractors' Association in Norway" (MEF), which has a sub-department forforest contractors united in MEF's Forest Division.

- "The Norwegian Forest Owners' Association” (NFOA). This is a national umbrella organization for four forest owner cooperatives as well as the Norwegian Forest Owners' Association.

Through MEF we expect to gain access to approx. 100 managers of companies who are forest contractors and through the four forest owners’ cooperatives, we are able to access around the same amount of “Forest management leaders.” These two stakeholder groups have been identified as key people who have an in-depth overview of the forest work processes and understanding of how to utilize new connectivity solutions in these processes. Additionally, they also have insights into what must be in place in terms of successful implementation of new connectivity solutions.

Survey data analysis (QCA)

Analysis of data generated through interviews and filled in survey questionnaires (including expanded survey) will be performed, preferably through frequency descriptions, statistical relationships between variables, and as well as through Qualitative Comparative Analysis (QCA). Charles Ragin, who originally developed QCA, explicitly designed it for analysis of medium-sized samples – those too large for in-depth case studies but too small for regression analysis [29]. Moreover, QCA is a well-suited analytical technique to be combine with qualitative data, i.e., mixed method. The aim of the interviews is to get a more in-depth understanding of the potential impact on the stakeholder's business impact (private) and societal impact (public). This insight will therefore complement the QCA methodology and strengthen the approach. For research that operates with smaller sets of survey data, which at the same time has access to in-depth qualitative data from the same field (as the case in COMMECT), knowledge from the qualitative study may give useful inputs to the focus in the QCA, and at the same time complement the interpretation and understanding of QCA results. QCA is therefore a well-suited approach for analysis in the project. The QCA findings will also give valuable insight that also relates to companies' business model activities and therefore contribute to how the deployment of new connectivity solutions for the stakeholders engaged in the Living Lab ecosystem could be designed.

The connectivity solutions tested in the COMMECT project involves complex processes, multiple stakeholders and various factors that can influence its effectiveness. As a result, evaluating which conditions need to be in place to achieve high levels of positive impact can be challenging. QCA is a useful method for this type of evaluation because it allows researchers to examine different configurations of conditions and their relationship with the outcome of interest. Thus, it is particularly relevant for COMMECT, where different stakeholders in different Living Labs may face different constraints and require different support to utilize the connectivity solutions most effectively. The comparability benefit in QCA allow us to compare configurations between the different Living Labs or between different stakeholder groups. QCA is also useful because it can identify necessary and sufficient conditions for a specific outcome of interest, in this case the socio-economic impact from connectivity solutions. This can help researchers and stakeholders prioritize which conditions are essential for achieving high levels of positive impact and which ones may be less critical. By identifying multiple causal "recipes" associated with the outcome of interest, QCA can provide valuable insights into which configurations of conditions are most effective in achieving the desired results.

One specific QCA model could investigate the role of 5 relevant conditions and their impact on the social impact (benefits) of the implemented connectivity solution. Conditions to be explored could be (indicators from the survey questionnaire): 1) Level of collaboration with external partners, 2) innovation orientation in the department, 3) Attitude toward the adoption of new technologies, 4) Competences on the new technology implemented and 5) Level of support on the new technology implemented. Below is an example of how the results could look (Table 6). The results show how 3 different routes can lead to high levels of social benefits in use of the new technology and how certain factors must be in place to reach a successful outcome.

Table 6: Result example: How to gain high level social impact (benefits) from new ICT solution

Route	Collaboration with external partners	Innovation-orientation	Attitude toward the adoption of new technologies	Competences technology	Technology Support
1	●		●	●	
2	○	●	●	●	

3		●	●	○	●

*Notes: Black circles "●" = has to be in place. White circles "○" = should not be in place. Blank cells indicate an irrelevant ("don't care") condition.

The results reveal that a positive attitude towards new connectivity solutions are necessary for all routes to success. In addition, either collaboration or innovation is needed. Moreover, if not competences are in place, they need technical support.

Overall, QCA is a relevant and useful method for evaluating the effectiveness of utilizing new connectivity solutions to achieve high levels of positive impact. It allows researchers to consider multiple factors and their interactions, which can be crucial for understanding complex technologies like those investigated in COMMECT. By identifying necessary and sufficient conditions and multiple causal recipes, QCA can provide valuable insights into how to optimize the use of technologies and ensure the best possible outcomes for all stakeholders involved.

Responsibilities and timelines

The plan is to conduct the survey once. Depending on the maturity of the connectivity solutions (concept descriptions, MVP's or more advanced prototypes) are developed, the timing of the survey will differ. Hence for some LL's the survey will be executed before and for others the survey will happen after trials/pilots of the connectivity solutions. The survey will be distributed in paper form during workshops in the Living Labs. Online versions will be available, when expanding the survey to larges samples beyond LL's. The survey template and attached consent form is available in Appendix 2.

Each of the Living Labs will have their own contact person for performing the micro level analysis. These contact persons will have the following responsibility:

- Adapt questionnaire/survey: Adapting survey templates questions from English to their native language and context of their LL.
- Interviews of stakeholders: Identify and recruit the respondents and execute face to face interviews (F2F) when most suitable
- Distribute survey questionnaires for larger samples, paper and online. Moreover, follow-up the input deadlines are fulfilled.
- Assessing and forwarding results from LL to head of micro level studies (TNOR): Report interview and survey data to TNOR responsible.

In Table 7 an overview of the timeline for the micro level study is presented. The activities and deadlines will be the guideline for the contact persons going forward. As shown in Table 7, the timeline for the alignment of the methodology across the LLs for the micro level impact analysis is paramount. For the Norwegian LL the execution of an extended sample analysis is planned for Q1 2024. A more detailed progress plan for a similar extended study in the other LL will be presented at the latest in deliverable D5.3.

Table 7. Timeline for methodology and micro level analysis in five COMMECT Living Labs

Domain	Activities	Deadlines
Impact assessment	• Methodology alignment with joint LL meeting to discuss implementation of Soc.-Econ framework in the five LL's	November 2023
	• Recruit respondents for F2F interviews and online survey (small or large sample). Update templates and context	
	• Verify existing Soc.- Econ. findings from stakeholders	

methodology alignment	• Develop timeline for implementation of Soc.- Econ data collection (Interview and surveys) in LL's.	December 2023
	• Modifications of generic methodology based on findings and pilots from the LL's	April 2024
Micro level analysis-extended (LL NOR)	• Finalizing sampling lists and go through the questionnaire in collaboration with MEF and NFOA associations	December 2023
	• Choice of software for distribution of the survey digitally	December 2023
	• Transfer questionnaire to digital software and perform test	January 2024
	• Distribution of survey to MEF and NFOA respondents	February 2024
	• Cleaning data, perform data analysis of findings, and report preliminary findings in deliverable D5.3.	April 2024
Micro level analysis (all LL's)	• Revise and test interview template based on Norway pilot. Agree with stakeholders for filling in templated at F2F/Teams meetings, workshop, or small sample surveys.	January 2024
	• Perform data collection from LL's and document findings	March 2024
	• Deliver findings from interviews and survey pilots in deliverable D5.3.	May 2024
	• Finalize small and large sample (extended) studies in LL's	May 2025
	• Deliver findings from updated studies in all LLs. Final report with future research suggestions (D5.6)	August 2025

2.4. Application of socio-economic assessment methodology at macro and micro level

Here we introduce empirical findings from both the macro and micro level analysis. For the former most available broadband connectivity data is found in Norway, Denmark and Luxembourg. For Turkey and Serbia, data was unfortunately not available in the extent to perform a study of the relationship between fixed/broadband coverage and community effects such as works and jobs per capita and number of home/outgoing workers. For the latter, we present preliminary findings on the socio-economic analysis for the five LLs in the four countries. The plan here is to follow up these findings with more extensive online surveys for a broader set of value chain stakeholders.

2.4.1. Macro level - fixed and broadband coverage and use in the different LL countries.

As can be seen from Figure 4 below, the availability and take-up of broadband varies both over time and across the COMMECT LL countries. For example, the number of fixed broadband subscriptions per 100 inhabitants more than doubled in Turkey from 2010 to 2022. Still, with around 45 subscriptions per 100 inhabitants, Norway and Denmark had about twice the number of subscriptions as Turkey (22.3) in 2022. Interestingly, while Turkey has fewer mobile broadband subscriptions per 100 inhabitants than Denmark, Luxembourg, and Norway, only Denmark had a higher mobile data usage per mobile broadband subscription in 2022. The data reported in figure 4 below is from OECD and excludes Serbia. However, Ratel [30] reports that while the number of fixed broadband subscriptions in Serbia is relatively low compared to the EU average, the number of mobile broadband subscriptions per 100 inhabitants was 96 in 2021, which is above the EU average.

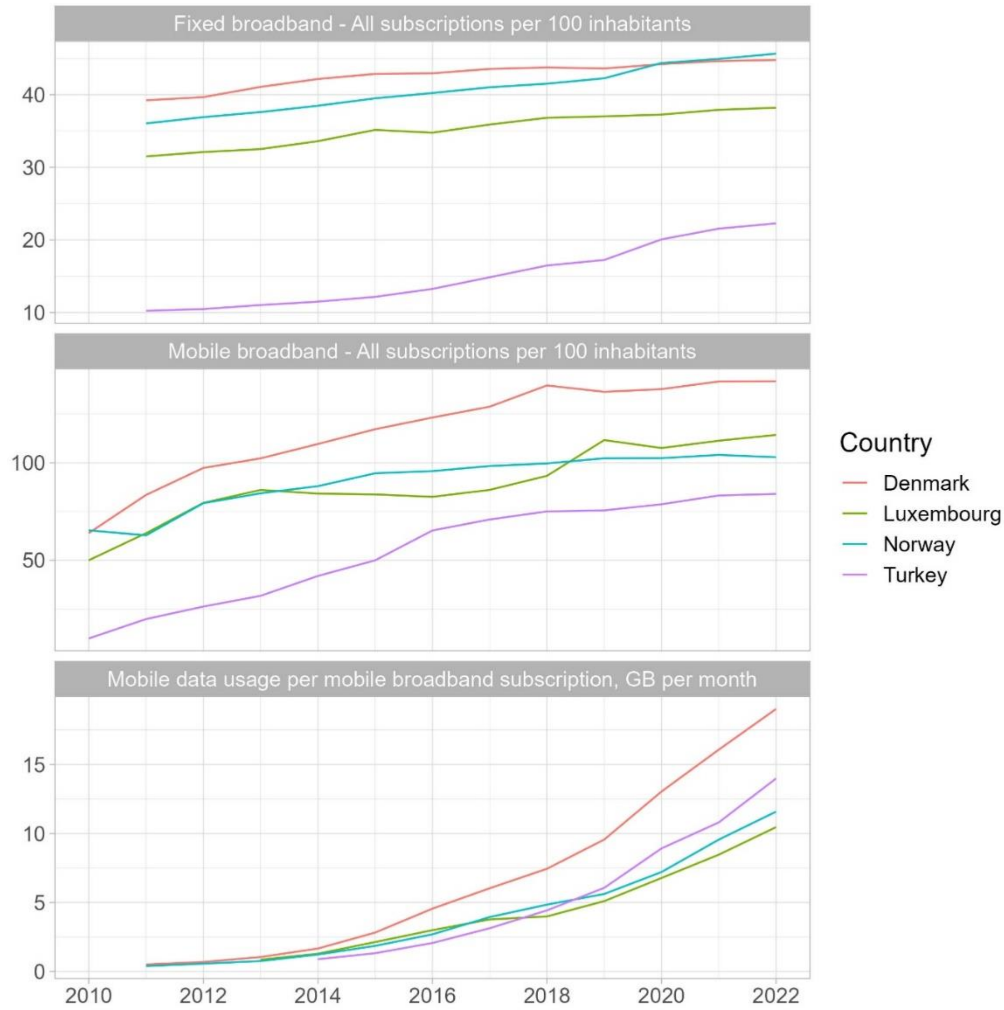


Figure 4. Development of use of fixed and mobile broadband. Source: OECDs Broadband Portal (https://www.oecd.org/digital/broadband/broadband-statistics/)

Data on the availability of fixed and mobile broadband is available for Denmark, Luxembourg and Norway through the DESI portal developed by the European Commission (EC). In Figure 5 below, we plot the development over time. For fixed broadband (labelled broadband) , we see that Denmark and Luxembourg have very high coverage rates also for speeds up to 1Gbit/s. The coverage in Norway is lower, but increasing significantly over time, especially for 1Gbit/s. Turning to mobile broadband (labelled LTE and 5G), we see that LTE coverage is near universal in all countries from 2015 onwards, but that there is more variation in 5G coverage with Denmark a clear front runner.

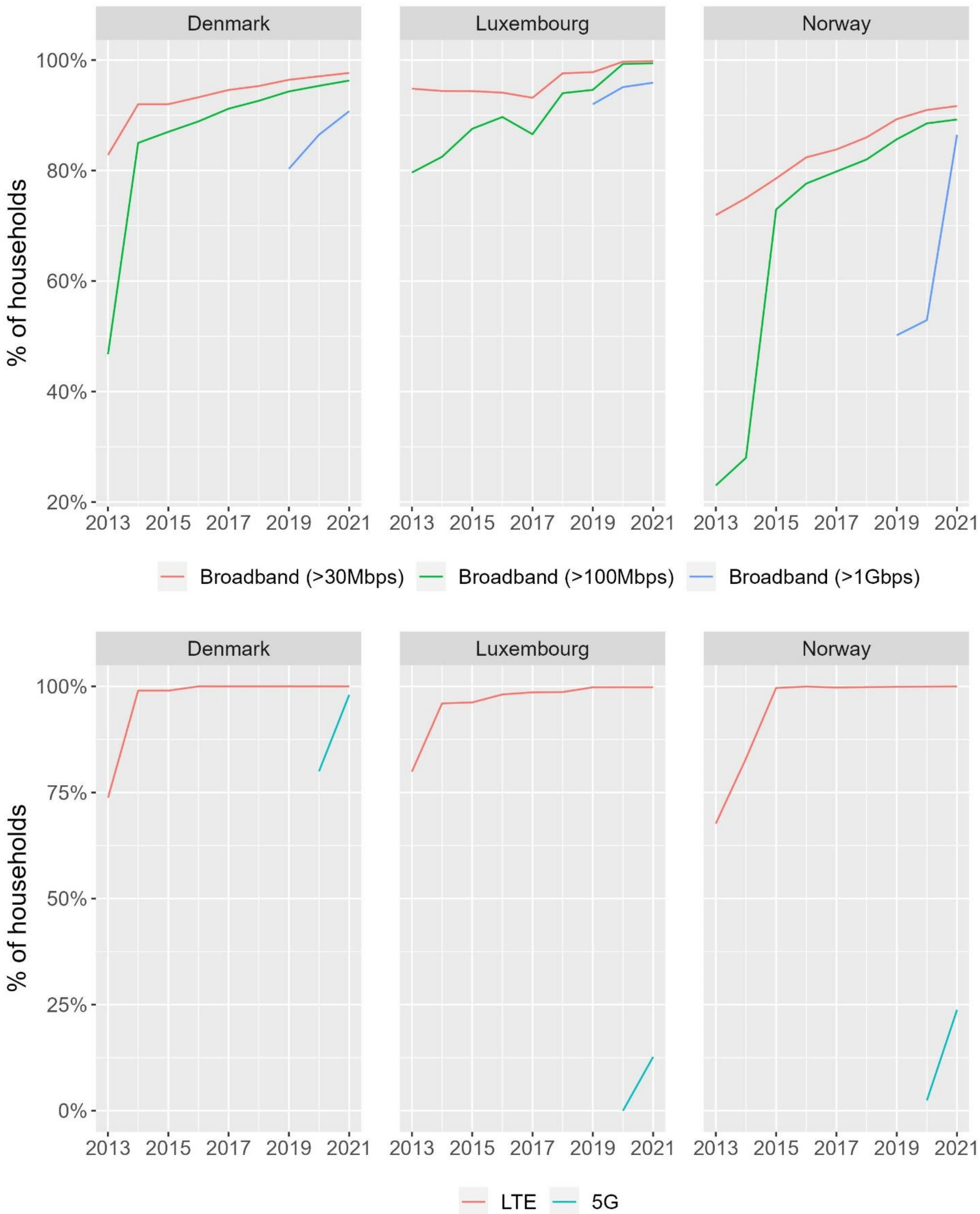


Figure 5. Development of fixed and mobile broadband coverage. Source: The Digital Economy and Society Index (DESI), EC (https://digital-decade-desi.digital-strategy.ec.europa.eu/datasets/desi-2022/charts)

We use the method outlined previously in 2.3.1 to estimate the effect of connectivity in a subset of the countries analyzed in the COMMECT project. Lack of comparable data meant that we could not include Serbia and Turkey in the analysis.

The application of the method is straightforward, but credible estimates of the effect of connectivity require detailed data. In particular one would need data on both connectivity (e.g., 5G or fixed broadband coverage) and the socio-economic outcomes of interest at the regional level. One would also need a data set that runs over time, to ensure that there is variation in both connectivity and the socio-economic outcomes over time.

Given the scope of the project, analyzing the effect of access to high-speed mobile connectivity would be especially relevant. Such analysis would also fill a gap in the existing research literature since much of the existing literature focuses on either basic phone connectivity or fixed broadband. Historical data of sufficient quality on the roll-out of 4G and 5G networks has proved difficult to attain for this research project. Our empirical applications therefore focus on the roll-out of fixed broadband. Data of sufficient quality was obtained for Norway, Denmark and Luxembourg and we therefore focus on these countries in the following. The data sources used in the analysis is as follows.

1. **Connectivity:** Broadband coverage data was obtained from The Luxembourgish open data platform (https://data.public.lu), the Norwegian Communications Authority (https://nkom.no/) and The Agency for Data Supply and Infrastructure (https://eng.sdfi.dk/). For each country there is information about the share of households in each municipality with access to different broadband speeds. For Luxembourg there is data for 2016 and 2018. The Norwegian data covers the period from 2000 to today, while the Danish data is available from 2014 and onwards.

2. **Socio-economic outcomes:** Data on employment and jobs were obtained from STATEC (https://lustat.statec.lu/), Statistics Norway (https://ssb.no) and Statistics Denmark (https://www.dst.dk/en).

2.4.2. Empirical analysis

Broadband connectivity may affect a wide range of socio-economic outcomes. In this study we focus on job creation in local communities, as well as the ability for people living in the municipality to work remotely (that is, in other municipalities). The choice of outcome variables is in part motivated by the availability of such data on the municipality level in several of the LL countries. We complement the existing literature by 1) distinguishing between rural and urban communities when estimating the effect of better connectivity, and 2) extending the analysis to the decade between 2010 and 2020 and estimating the effects of improvements in connectivity beyond basic broadband. Due to lack of comparable data we could not include Serbia and Turkey in the analysis.

Norway

We use yearly data obtained from The Norwegian Communications Authority (Nkom, 2021, retrieved from https://nkom.no/fysiske-nett-og-infrastruktur/offentlig-stotte-til-bredbandsutbygging) on the availability of broadband internet in Norwegian municipalities between 2000 and 2021. The data gives information about the proportion of households that have access to a certain bit-rate in given year. We have matched this data with yearly employment data available from Statistics Norway giving information about the number of people working in each Norwegian municipality and the municipality of residence for these workers. As illustrated in Figures 6 and 7 below 640kbit/s broadband went from virtually non-existent to almost universal from 2000 to 2011 with 50mbit/s displaying a similar pattern from 2011 to 2021. (The box represents the median value, while the dots represent single municipality data value points/year).

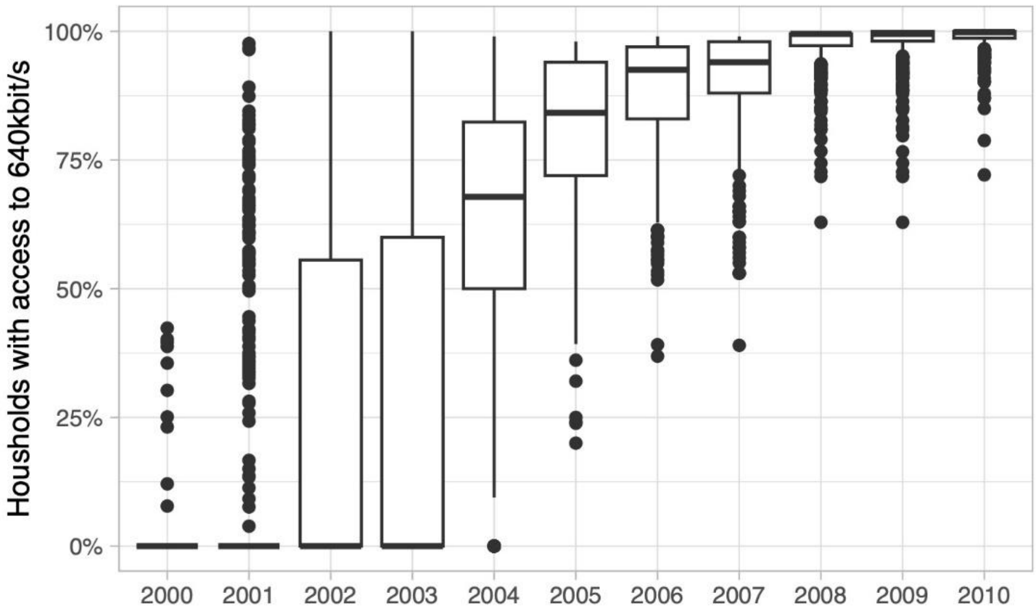


Figure 6. Broadband coverage in Norway, 2000-2010. The bar in the middle of each box represents the median coverage each year across Norwegian municipalities. Source: Nkom.

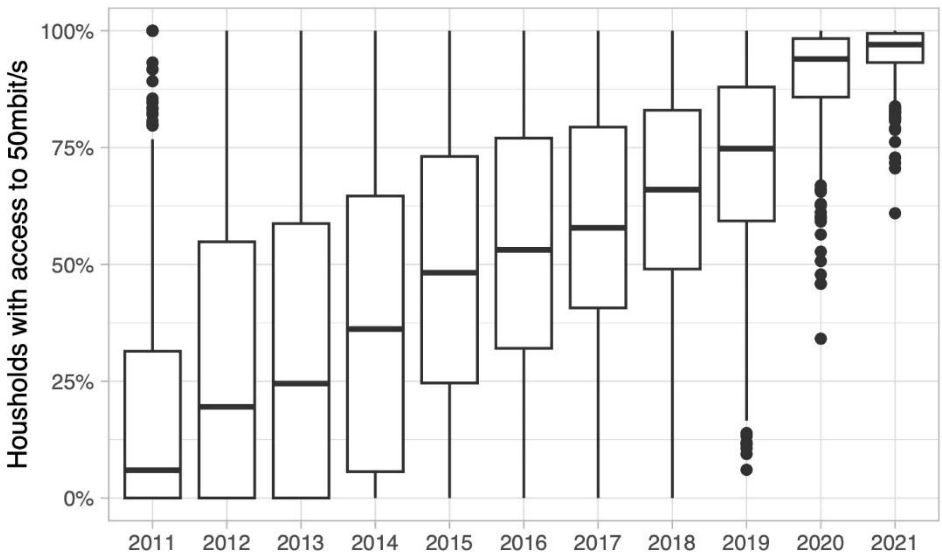


Figure 7. Broadband coverage in Norway, 2011-2021. The bar in the middle of each box represents the median coverage each year across Norwegian municipalities. Source: Nkom.

We consider the effect of broadband connectivity on the following outcomes:

- Workers per capita – The number of employed persons relative to the working age population in the municipality.
- Jobs per capita – The number of jobs in the municipality relative to the working age population in the municipality.
- Home workers – The number of people living and working in the municipality relative to the working age population in the municipality.
- Incoming workers (%) – The proportion of jobs in the municipality that are occupied by people living in other municipalities.

- Outgoing workers (%) – The proportion of the workers living in the municipality that work in other municipalities.

Because we are especially interested in the effect in rural communities, we estimate separate effects for rural municipalities (population less than 10.000). We estimate the following model:

$$y_{ir(i)t} = \alpha_{ir(i)} + \lambda_{r(i)t} + \sum\nolimits_{r=Rural,Urban} \beta_r \, D_{ir(i)t} + \varepsilon_{ir(i)t},$$

where $ir(i)t$ is an outcome for municipality i in year t and where $r(i) \in Rural, Urban$ indicates whether the municipality is urban or rural. $\alpha_i r(i)$ are fixed effects at the municipality level and $\lambda_r(i)t$ are year fixed effects, separate for rural and urban municipalities (allowing different trends in rural and urban municipalities). $D_i r(i)t$ is our measure of the broadband connectivity in municipality i in year t. Between 2000 and 2010, $D_i r(i)t$ measures the proportion of the households in the municipality with access to 604kbit/s fixed broadband internet. Between 2011 and 2022, $D_i r(i)t$ measures the proportion of households with access to 50mbit/s fixed broadband internet. The key parameter of interest is β_r, which estimates the effect of an increase in broadband coverage on the outcome in question. The subscript r indicates that we measure separate effects for urban and rural municipalities. The results of the model are reported in Table 8 below.

Table 8: The effect of broadband coverage on local employment in Norway

	Workers per capita	Jobs per capita	Home workers	Incoming workers (%)	Outgoing workers (%)
Time period: 2000-2010					
640kbit/s (%) x Rural	0.005+	0.001	0.005+	-0.001	0.000
	(0.003)	(0.004)	(0.002)	(0.002)	(0.002)
640kbit/s (%) x Urban	0.007*	0.018+	0.006+	0.009*	-0.001
	(0.003)	(0.010)	(0.003)	(0.004)	(0.003)
N	4658	4658	4658	4656	4656
Time period: 2011-2022					
50mbit/s (%) x Rural	0.000	0.005	0.000	0.004+	0.000
	(0.002)	(0.004)	(0.002)	(0.002)	(0.002)
50mbit/s (%) x Urban	-0.017	-0.015	-0.020	0.010	0.000
	(0.015)	(0.021)	(0.013)	(0.007)	(0.004)
N	4498	4498	4498	4494	4494
+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001					

Table 8 indicates that increased broadband coverage between 2000 and 2010, better broadband coverage led to higher employment rates (Workers per capita). The increase seems to come from an increase in home workers, rather than an increase in outgoing workers. In urban municipalities there is an increase in the proportion of jobs occupied by persons living in other municipalities (Incoming workers (%), and some evidence for an increase in the jobs per capita. In the period 2011-2022, there is less evidence of an effect of increased connectivity. There is some indication of an increase in the proportion of incoming workers in rural municipalities, but the statistical evidence is not very strong. Taken together, the results indicate that better connectivity leads to job creation both in rural and urban communities and that the provision of basic broadband connectivity (640kbit/s) in the early 2000 was more important than the subsequent Improvement In speed from 2011-2022.

Denmark

In this section we turn our attention to Denmark and perform a similar analysis as above. For Denmark, we have data on fixed broadband coverage at different speeds in the period 2014-2021. As seen from figure 8 below, access to 2mbit/s was already high in 2014 and became close to universal towards the end of the period. Access to 10mbit/s also became near universal during the period. For 100mbit/s, access was more restricted in 2014, with a number of municipalities having a coverage rate below 50%. Over time access has improved significantly, and in 2021 coverage is above 60% in all municipalities and the median municipalities has a coverage above 90%.

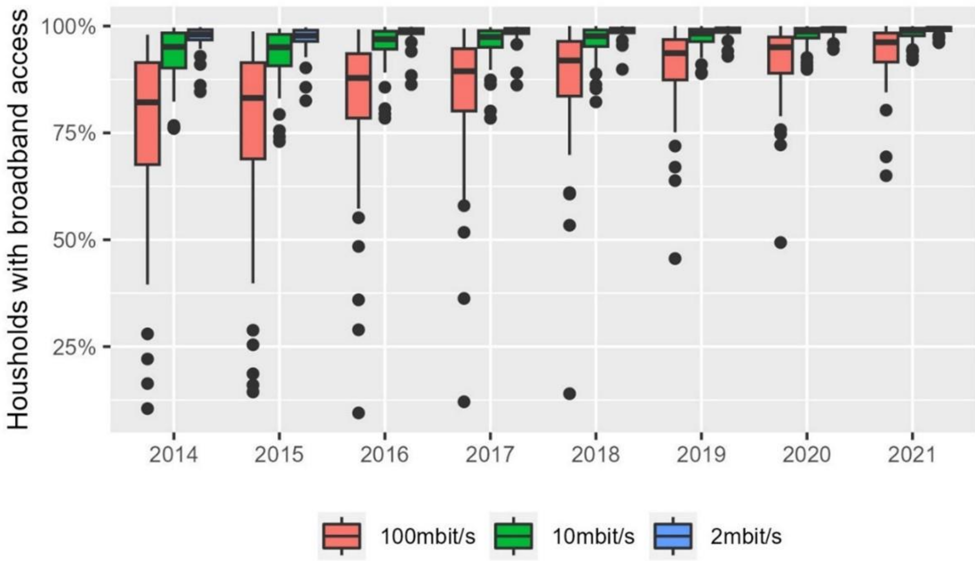


Figure 8. Development of broadband coverage in Denmark. Source: Statbank, Denmark

We obtained municipality level data on labor market outcomes from Statistics Denmark (https://www.statbank.dk/20312) and estimated a model of the same form as for Norway. We were able to obtain data on Workers per capita and Jobs per capita as defined above and focus on these variables. Because availability of 2mbit/s and 10mbit/s was very high in the entire period, we use access to 100mbit/s as the explanatory variable. As reported in Table 9 below, we find strong evidence of a positive effect of increased access to fast broadband internet on both Workers per capita and Jobs per capita. For Jobs per capita, the effect is only present in rural municipalities (i.e., municipalities with a population above 20000).

Table 9: The effect of broadband coverage on local employment in Denmark

	Workers per capita	Jobs per capita
100mbit/s (%) x Rural	0.027***	0.032***
	(0.004)	(0.009)
100mbit/s (%) x Urban	0.020***	0.015
	(0.005)	(0.013)
N	772	772
+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001		

Luxembourg

For Luxembourg, broadband coverage data was only obtained for the years 2016 and 2018 (https://data.public.lu/en/datasets/cartes-de-couverture-des-reseaux-de-communications-electroniques/). As illustrated in Figure 9, we see that the coverage for 30mbit/s is near universal in most municipalities in both 2016 and 2018. There is more variation in the access to both 100mbit/s and 1000mbit/s, and there is an increase in both measures from 2016 to 2018

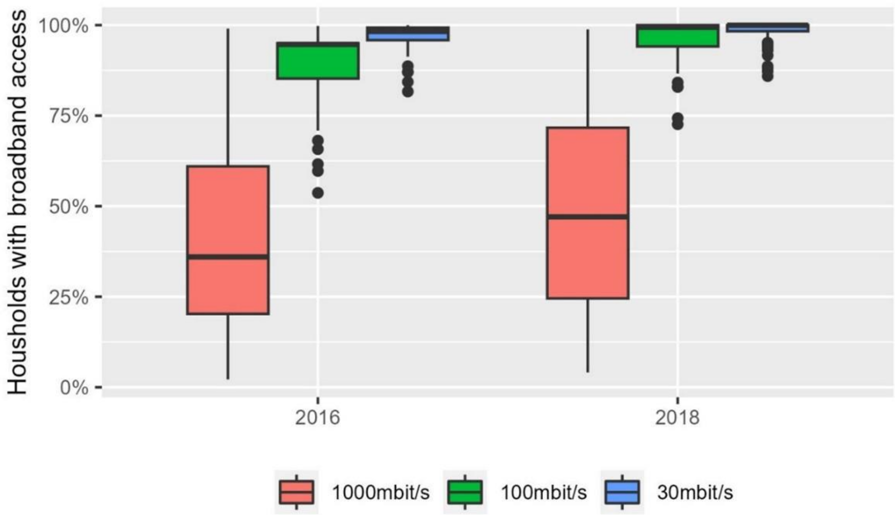


Figure 9. Development of broadband coverage in Luxembourg. Source: https://data.public.lu/en/datasets/cartes-de-couverture-des-reseaux-de-communications-electroniques/

As for Denmark we focus on the 100mbit/s in the regression model. We were only able to obtain data for Workers per capita and focus on this variable. The other socio-economic outcome dimensions (jobs per capita as well as incoming and outgoing workers) were not listed in the public statistical agency (Luxembourgish open data platform). (https://lustat.statec.lu/?lc=en&pg=0&fs[0]=Topics%2C1%7Cpopulation%20and%20employment%23B%23%7Clabour%20market%23B5%23&fc=Topics). As we see from Table 10 below, although the coefficients are positive, we do not find a statistically significant effect of broadband coverage on Workers per capita. This is perhaps not surprising given the limited time span for which we have data.

Table 10. The effect of broadband coverage on local employment in Luxembourg

	Workers per capita
100mbit/s (%) x Rural	0.016
	(0.022)
100mbit/s (%) x Urban	0.018
	(0.022)
N	177
+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001	

2.4.3. Conclusions and next steps

When analyzing the effect of increased broadband connectivity on labor market outcomes, we find positive effects in both Norway and Denmark. The positive effect was found to be especially strong in Denmark. For Luxembourg, the time span for which we were able to obtain data was very limited, and for Serbia and Turkey we were not able to obtain sufficiently detailed data to perform a statistical analysis.

Future studies should first of all examine the possibilities for including fixed broadband coverage data as so to analyze potential effects using the dimensions selected for this study (workers per capita, incoming/outgoing workers) on a regional/national level. Moreover, follow-ups studies should also seek to include longer time series, preferably a five- or 10-year span. Furthermore, another interesting venue for future research is to study the impact of the roll-out of mobile broadband (4G and 5G) on the socio-economic outcomes applied in the present study. Additionally, portfolios of other socio-economic outcome dimensions should also be identified and included in a follow-up study applying the research methodology as described.

2.5. Micro level – Socio-Economic impact dimensions in the different LL countries

In order to align the socio-economic impact indicators per LL and across the LL's, hence remove inconsistency related to impact indicators reported in different tasks/deliverables, as well as preparing for a broader survey, TNOR (responsible for the socio-economic analysis task) together with TNO (responsible for the business model analysis task) in T3.1, performed a joint study among the LLs in June 2023. Moreover, the objective was to effectively capture the expected socio-economic impact for potential end-users per Living Lab (which may differ between private organizations, inhabitants of an area, local communities, research organizations or government institutions), other relevant stakeholders for the Living Lab can be involved as well. The respondents were the LL heads, or representatives substituting the head.

A semi-structured interview (see Table 11 below) guide was used, which also included questions related to business model aspects with stakeholders and to elicit qualitative insights on how the business models supporting connectivity solutions should be configured. The latter findings will be reported in the D3.3 report. The interviews took place during June 2023 – Norway LL (June 13th), Turkey (June 14th), Serbia LL (June 15th) and Denmark (June 20th).

Table 11. Interview guide questions for initial study of impact and business models in LL's

Sections	Type of questions
Introduction	• What is your role in COMMECT and what objectives do you intend to achieve as part of your Living Lab?
General questions	• What connectivity solutions do you intend to realize as part of the Living Lab? • What use cases are enabled through this solution? • What end-users do you consider for these use cases within the Living Lab? • What are the characteristics of the end-users? How would you categorize these end-users? • What problems are they facing and what are their needs?
Questions for socio-economic aspects	• How do you expect that the use cases will 'solve' or address the problems or needs faced by end-users? • What value will be created for end-users? What value will potentially be destroyed or what will end-users have to do, or what can they do differently? Why? • What can we say about the potential adoption of use cases under these conditions? Is this sufficient? Why? • What societal value can be expected if connectivity solutions are realized? Why is this the case? To whom is this relevant?

Questions for business model aspects	• Who will be involved to realize the connectivity solutions? • How will these connectivity solutions be monetized long-term? • What other stakeholders are considered relevant in terms of the use cases? Why is this case? What value will they bring and receive? • Would these stakeholders be valuable to include as part of realizing connectivity solutions?

Each interview is recorded if approved by the Living Lab leader; otherwise, the interview will be documented by means of taking minutes. The transcripts for the interviews are coded and analyzed using *content analysis* [31]. Accordingly, researchers from TNO and TNOR independently go through the transcripts and highlight themes or topics discussed in the context of business and / or socio-economic aspects. These themes and topics are then compared to the categories of socio-economic and business aspects identified in previous research as well as cross-compared across Living Labs. Consequently, the themes can be concretized, either by identifying that a similar theme has been proposed before (for example, socio-economic impact related to *creating a sense of community through connectivity solutions*) or may warrant a new theme adding to literature (i.e., *forest protection through connectivity solutions*). Once completed, the themes are validated with the Living Lab leaders and can be further concretized through KPIs and metrics to be measured throughout COMMECT.

The questions related the socio-economic impact that can be expected through the deployment of enhanced connectivity supported solutions, and thereby the enabled use cases, for stakeholders in the various Living Labs. These questions target understanding the purpose of realizing the use cases for various stakeholder groups, as well as a general discussion on how connectivity solutions may create value for stakeholders in its vicinity. Here, capturing the narrative of *why* and *how* a use case creates value is important to distill socio-economic aspects. Based on these semi-structured interviews with Living Lab stakeholders, we developed the following (initial) set of socio-economic indicators (KVIs) which should be considered in light of the Living Lab context throughout COMMECT (as described in Table 12 below). To identify these, we built upon the list of KVIs proposed in the previous section.

Table 12. Socio-economic impact indicators in D3.1

Socio – Economic impact indicators	**LUX**	**NOR**	**DEN**	**TUR**	**SER**
Profitability (Econ)	x	x	x	x	x
Operational efficiency (Econ)	x	x	x	x	
Product quality (Econ)	x	x	x	x	x
Ease of use of technology (Social)		x	x	x	
Attractiveness/well-being of community (Social)	x		x	x	x
Access to digital technology/connectivity/data (Social)		x	x	x	x
Education and training of stakeholders (Social)	x			x	x
Increased safety (EHS) for stakeholders (Social)		x	x		
Improved stakeholder collaboration (Social)		x	x		

Table 12 shows a range of different societal and economic indicators for the different Living Labs. For the economical ones, it is related to the business impacts for multiple actors in the value chain. For the societal ones, it is also related to community, e.g. access to residents and visitors of the municipalities, beyond the core value chain actors. In Table 12 we have grouped these dimensions and their presence in the five LLs. These dimensions and indicators are well aligned with some of the ones presented in the state-of -the art review section of this document.

For example, if we draw upon the Danish Living Lab, we observe that through the deployment of connectivity solutions socio-economic impact can be created for logistic companies (value creation mechanism), as they are able to better monitor the condition of piglets during transport. To support the realization of these connectivity solutions (and these effects), it can subsequently be expected that the logistic company would be willing to (partially) finance the proposed solutions. Here, the additional economic impacts related to reduced operational costs for veterinarians as well as a strengthened collaboration (as data can real-time be transmitted) could encourage or incentive municipalities or veterinarians to partially support the deployment of connectivity solutions. These value creation and capture dynamics will be explained as part of the business models proposed, and thus serve as a starting point for stakeholders to discuss how the solutions can be realized in practice.

The survey questionnaire we plan to submit to a broader set of stakeholders in all the living labs will include these indicators displayed in Table 12 together with others found from the literature and research project review. Here we also seek to collect information on the degree of impact. This will be done using a five-point Likert scale where a low or high degree of impact will be assessed by the respondent. In addition, we will also introduce other aspects, such as degree of novelty/innovation, approach to agile development practices and degree of collaboration with array of stakeholders regionally as well as internationally. See more details in the survey questionnaire attached in Appendix 1. Next step for the business model design approach is to perform interactive workshops with business model stakeholders in order to map the roles and responsibilities of all stakeholders involved in light of connectivity deployment and use case realization. Through this, the goal is to make decisions on how value is created (i.e., are the use cases valuable for end-users? What other benefits can be considered?) as well as captured (i.e., who makes what investments, how is value exchanged or distributed between stakeholders?

2.5.1. Conclusions and next steps

In Chapter 2 we have presented a methodology for how to validate socio-economic impact from innovative connectivity solutions enabled by next generation digital technologies in rural areas communities. The methodology separates the validation into two levels (macro and micro) of analysis. Preliminary findings show a significant relationship between enhanced fixed broadband coverage and social outcomes on a macro/regional level in several EU countries. We also present expected impact indicators from stakeholders in different forest -and agricultural businesses on a use case level in the same countries. These findings add insight to the concept of validation of impact from adoption of digital technology for businesses and individuals outside cities and urban communities. The micro level analysis so far is limited to a small sample of stakeholders. A large sample online survey study later in the project will be performed that will enable us to present more robust findings on a use case level and a more in-depth study of the degree of impact the array of impact indicators. For the macro level analysis, the nest step is to study roll-out of mobile broadband on the socio-economic outcomes, including longer time series, preferably a five- or 10-year span. Additionally, portfolios of other socio-economic outcome indicators should also be identified and included in a follow-up study applying the research methodology as described. The remaining resources will however be preferred allocated on the micro level studies going forward. We recognize that our suggested impact assessment methodology may have limitations and shortcomings. We will focus on single measurements (ex-ante) of impact indicators and not perform both ex-ante and ex-post assessments as done in relation to other EU funded research projects. We do however include both quantitative and qualitative techniques, and we do operate on different context levels, macro as well as micro. However, we will address the potential need for revisions of our methodology in the next deliverable – D5.3 Report on the Socio Economic and Environmental Impact in the Living Labs, version 1. This revision will be based on experience and learnings from our combined qualitative and qualitative research approach. This includes the availability of quantitative data, timing of an access to larger sample of stakeholders for survey studies and outputs from experimenting with connectivity solution pilots. Moreover, updated lessons learned from other similar EU research project will be introduces in the methodology revision as well.

3. Environmental Assessment Methodology

3.1 Introduction to LCA methodology

To evaluate the environmental sustainability of products, processes, services or even organisations, the most consensual methodology is **life cycle assessment (LCA)**. LCA is standardised by ISO 14040/44 [32] and can provide a comprehensive evaluation following the life cycle stages of the studied system and considering a large panel of environmental indicators. This allows identifying the potential shift of environmental burdens. LCA can be applied to support the eco-design of a new product, to define environmental benchmarks, to label a product, or to even support policymakers. In COMMECT, LCA is applied to develop the most environmentally friendly connectivity solutions (digital solutions) and to understand how far they can contribute to climate change mitigation and other sustainability targets. ISO 14040/44 standards are derived into other specific standards, e.g., ISO 14067 for carbon footprint, ISO 14046 for water footprint, ISO 14025 for environmental product declaration, or for the Environmental Footprint (EF) method developed by the European Commission (EC) to harmonize the calculation of environmental performance of products and organisations.

LCA methodology is divided into four main steps. The first phase, **goal and scope definition**, is important to detail the objectives and settings of the LCA study, in particular the definition of the studied scenarios, the system boundaries, the functional unit (quantified function to normalize results), the selected environmental indicators and other requirements for modelling. During the second step, **life cycle inventory (LCI) modelling**, the inputs (e.g., consumption of energy) and outputs (e.g., generated waste) are quantified for the evaluated scenarios. These specific data, called foreground data, are complemented with generic background data to reflect upstream and downstream processes (e.g., supply chain of a raw material). LCI results are all the emissions and natural resources, i.e., environmental exchanges, quantified for the defined functional unit. These are translated into environmental impacts via the third step of **life cycle impact assessment (LCIA)**. LCI flows are classified and characterized depending on their effects, using a characterization factor expressed according to the unit of reference for the impact category (e.g., kg CO_2 eq. for climate change impact). Finally, the **results interpretation** phase analyses the outcomes to draw conclusions depending on the study goals, using contribution, gravity, sensitivity and/or uncertainty analyses. The outcomes can be used to refine the assumptions or data defined in one of the three previous steps in an iterative manner.

3.2 Life cycle impacts of connectivity solutions applied to agricultural sectors

To operate and provide ad hoc services, connectivity solutions need the following sub-systems, which need to be considered when performing the life cycle impact assessments [33]: the end-user devices, the customer premise equipment, the network and its infrastructure, the data transmission equipment, and the data centers and servers.

From a life cycle perspective, while around two-thirds to three-quarters of the carbon footprint on average, could be attributed to the manufacturing of the end user devices using the ICT solution(s), a remaining one-quarter to one-third of the carbon impact, on average, is coming from the operation phase and infrastructures, equipment and network needed to exchange data [33]/ For the operation phase, the carbon impact is distributed between the powering of the end user devices (around 10% of the total impact), the 4G LTE network (around 10 to 12% of the total impact), and the data centers and servers (around 5 to 10% of the total impact).

Interestingly, connectivity solutions can provide more precise spatial and temporal information which would inform optimal decisions for growers. This will particularly contribute to the reduction of chemicals or water consumption and thus mitigate the environmental impacts of viticulture [34]. Also, precision agriculture enabled by ICT / connectivity systems, can increase farming efficiency, and thus reduce the environmental impact of agriculture [35]. However, the implementation of these solutions requires the production and utilization of new technology, generating additional environmental impacts (first-order effects, see section 3.3), which should be lower than the previously mentioned benefits (second-order effects, see section 3.3) to avoid trade-offs [35].

For instance, within the set of activities that falls under precision agriculture, precision livestock farming (PLF) is becoming more important in the farming sector. There are very few LCA studies on PLF impacts, as highlighted by the review studies from Lovarelli et al. [36] and Tullo et al. [37]. Tullo et al. [37] found that the main purpose of PLF applications is often not for mitigating environmental impacts, however, this can often be seen as a co-benefit due to increased productivity, reproduction, and improved animal health. The recent LCA study by Pardo et al. [38] on a PLF solution for intensive dairy goat farms in Spain highlighted a reduction of the overall environmental impact. The one by Todde et al. [39] on PLF applied to dairy production also highlighted environmental benefits, although emissions and energy production increased during milk production, the latter are compensated by the lower impacts during the cheese production stage (better milk separation). This shows the important of applying a life cycle perspective.

While connectivity solutions are increasingly being applied to agricultural activities, their impacts – considering both first- and second-order effects - is not fully considered in the existing LCAs of farming-related activities powered by ICT equipment and networks, and it is of the utmost importance to clarify the system boundaries (i.e., the in-scope and out-of-scope) of LCAs of farming activities using ICT equipment and network, as detailed in the following sub-sections.

For example, among the three precision agriculture technologies used to support and enhance the production of nectarines in Spain [40] – namely, (i) guidance systems, (ii) recording technologies, and (iii) reacting technologies – the LCI did not include the components of the ICT solution, and therefore their associated impacts (first-order effects) rather it compared the differences between the application of water, fertilizers, and pesticides (second-order effects only). Similarly, on a recent comparative LCA between an autonomous robot and a conventional tractor performing chemical and mechanical weeding tasks [41], neither the impact of the global navigation satellite system (GNSS) nor relay antennas for the global system for mobile (GSM) communications were considered in the study. Another study evaluated the environmental impact of precision agriculture in the production of sugarcane [42]. While the implementation of the GNSS system in their case was beneficial to reduce soil compaction and improve the application of fertilizers and mechanical harvesting (second-order effects), the impact associated with the GNSS system infrastructure, equipment, and network (first-order effects) was not considered. Lastly, a recent LCA of a nitrogen monitoring system for wheat in Austria included part of the ICT system [43]: the data traffic required to fertilize one hectare of cropland (1.45 GB/ha) as well as the electricity required to transfer this data via internet (0.104 kWh/ha); however, the laptop manufacturing and the energy necessary to power the laptop, was excluded from the study.

3.3 LCA methodology for the COMMECT project

For the evaluation of digital or connectivity solutions developed in the COMMECT project, besides LCA standards, the recommendations of the EC for the Environmental Footprint (EF) will be followed. This implies that a pre-defined set of environmental indicators will be applied. The EF method [44] includes 16 impact categories covering the effects on climate change, human health, ecosystems and resources (Table 13). To facilitate the interpretation, the environmental impacts can be aggregated into one single score using normalization and weighting datasets provided by the EC [45]. This **aggregated EF score** could be used as an **environmental KPI** in the COMMECT project, together with a KPI focusing on **climate change** (widely used indicator), while the detailed analysis on the 16 categories will still be performed to understand potential trade-offs.

Table 13. Environmental impact categories and their description following EF method

Impact category	Acronym	Unit	Description
Climate change	CC	kg CO_2-eq	Radiative forcing of GHGs over 100 years
Ozone depletion	OD	kg CFC-11-eq	Destructive effects on the stratospheric ozone layer over 100 years
Ionizing radiation	IR	kBq U235-eq	Human exposure to radioactive material
Photochemical ozone formation	POF	kg NMVOC-eq	Tropospheric ozone concentration increases due to VOCs oxidation
Particulate matter	PM	disease inc.	Disease incidence due to particulate matter emissions
Human toxicity, non-cancer	HTnc	CTUh	Increased non-cancer cases in human population
Human toxicity, cancer	HTc	CTUh	Increased cancer diseases in human population
Acidification	Ac	molc H^+-eq	Critical load exceedance in terrestrial ecosystems due to acidifying substances deposition
Eutrophication, freshwater	FEP	kg P-eq	Increase of phosphorous concentration in water
Eutrophication, marine	MEP	kg N-eq	Increase of nitrogen concentration in water
Eutrophication, terrestrial	TEP	molc N-eq	Critical load exceedance in terrestrial ecosystems due to eutrophying substances deposition
Ecotoxicity, freshwater	FET	CTUe	Potentially affected fraction of species in freshwater
Land use	LU	-	Index of soil quality
Water use	WU	m^3 depriv.	Deprivation-weighted water consumption
Resource use, fossils	FR	MJ	Fossil resources depletion based on lower heating values
Resource use, minerals and metals	MR	kg Sb-eq	Mineral and metals resource depletion based on use-to-availability ratio

Regarding the impact assessment of soil quality, which is relevant to some LLs, EF v3.1, only includes a generic soil quality index (an aggregation among several indicators). The soil quality index for the LLs will be provided in WP5, but the integration of the specific soil quality measurements is out of scope for the project. Indeed, this type of data is not commonly integrated in LCA but potential improvements of soil quality from the use cases could still be discussed qualitatively together with the LCA results.

The EC does not define specific category rules for the ICT sector. However, specific ICT standards were developed by the European Telecommunications Standards Institute (ETSI) and the International Telecommunications Union (ITU). ETSI is one of three standardization organizations recognized by the European Commission, and the ITU is an agency within the United Nations. The ETSI and ITU methodologies for the LCA of ICT goods and services (ETSI ES 203 199 and ITU-T L.1410) serve as a complement to the ISO 14040 and 14044 standards for LCA and are considered technically equivalent as they were developed in tandem [46] [47]. It is worth noticing that industry or industry groups, such as Deutsche Telekom, British Telekom, the Italo-Brazilian telecommunications group TIM, the Alliance for IoT and Edge Computing Innovation (AIOTI) and the Next Generation Mobile Networks Alliance (NGMN), have also developed their own methodologies. The latter rely on previously defined standards, e.g., AIOTI methodology [49] follows the recommendation and definitions provided by European Green Digital Coalition (EGDC) and uses the ITU-T L.1410, ITU-T L.1333 and ITU-T L.1480 as a basis. The **ITU-T and other related LCA standards** will be used for the environmental sustainability evaluation within COMMECT, the correspondence with other industrial guidelines will be mentioned when relevant.

The different levels of connectivity impacts (see Figure 10) are detailed below.

Taxonomy described in this paper			Alternate taxonomies			
Effect	**Scope**	**GPS System Example**	**Hilty**	**Berkhout & Hertin**	**Williams**	**Rattle**
Embodied energy	Direct	Energy to produce a GPS system	1^{st}-order	Direct effects	ICT infrastructure and devices	
Operational energy		Energy to operate a GPS system				
Disposal energy		Energy to dispose of a GPS system at end-of-life				
Efficiency	Indirect: Single-service	More efficient traffic flow due to GPS-enhanced routing	2^{nd}-order	Indirect effects	Applications	Optimization
Substitution		Replacement of paper-based maps				Substitution
Direct rebound		More travel due to lower cost of traffic congestion	3^{rd}-order	Structural & behavioral effects	Effects on economic growth and consumption patterns	Induction
Indirect rebound	Indirect: Comple-mentary services	Energy consumed during time saved by more efficient travel				Supplement-ation
Economy-wide rebound (Structural change)	Indirect: Economy-wide	GPS enables autonomous vehicles and causes growth of intelligent transportation system manufacturing				Creation
Systemic Transformation	Indirect: Society-wide	Autonomous vehicles alter patterns in where people choose to live and work			Systemic effects on technology convergence & society	

Figure 10. Taxonomy to describe the different level of impacts of ICT [49]

First-order impacts

Connectivity solutions implies the deployment and use of several components: the terminals (e.g., sensors, smartphones), the network, and the datacenters. The environmental impacts of ICT solutions thus include the impacts along the life cycle of these components, from the production processes (e.g., supply chain to produce a base station and all its components) to the use (e.g., energy consumption of the base station) and disposal (e.g., treatment of the base station waste). For a specific connectivity / ICT function (e.g., transferring 1 GB of data to users in a specific region), different ICT systems can be compared depending on these life cycle impacts. These are referred to first-order effects in the ITU-T L.1410 standard since they correspond to the **direct effects of deploying ICT** (International Telecommunication Union 2014). For the use phase of network, the standards ITU-T L.1333 can be used, which focuses on the network carbon intensity derived from the energy consumption during the operation phase, normalized by the total data traffic.

Second-order impacts

Connectivity solutions can also have **enabling effects** in the sector of application. Indeed, the use of connectivity solutions can be aimed to optimize a specific process (e.g., more efficient workflows) or substitute material flows (e.g., switching from mail to email). These so-called second-order effects constitute indirect impacts since the system boundaries are expanded beyond the ICT sector to the life cycle of the sector of application (e.g., industry, transport, agriculture).

The calculation of second-order impacts thus refer to the difference of environmental impacts between the reference system without connectivity and the system functioning with connectivity, as described by ITU-T L.1410 for a certain environmental impact EI_i (e.g., climate change impact), as seen in Equation 1.

Eq. 1
$$EI_{\Delta,i} = EI_{reference,i} - EI_{ICT,i}$$

The environmental impact should refer to a relevant functional unit for the sector of application, e.g., the supply of 1 kWh of electricity if ICT is used to optimize the electricity grid. The second-order evaluation should thus focus on the changes induced to the reference scenario thanks to the connectivity product or service, e.g., difference on the use of transport, energy, material, or on the generation of waste. Second-order effects can be shown per life cycle phase or per good or service category.

Equation 1 is also supported by the World Resources Institute [50]. The latter, focusing on greenhouse gas (GHG) emissions (i.e., climate change impact), refer to the calculation of avoided emissions, i.e., anticipating that connectivity solutions create environmental benefits, and does not make the distinction between first- and second-order effects. This distinction is nevertheless important to be aligned with existing standards, as well as to follow GHG protocol recommendations [51].

Third-order impacts

The ITU-T and ETSI standards focus on first- and second-order impacts. They nevertheless mention other potential systemic effects, which are referred to as third-order impacts in [52]. The large-scale adoption of ICT solution can induce structural and behavioural changes. The rebound effect is one key component of third-order impacts. It implies that because of a better efficiency, the product/process is used more (cheaper operation). An example of the rebound effect is a person working from home who will still use his/her car to do other activities thanks to additional available time. Indirect rebound effects can also exist, e.g., the money saved by teleworking (no commuting costs) is used to buy a plane ticket for holidays. Systemic transformation is another part of potential second-order impacts, e.g., the high penetration of teleworking encourages people to live further away from their work, thus affecting urban planning. Systemic effects are usually covered in LCA when adopting a consequential approach [53] to understand the large-scale consequences of the deployment of a product or service. Third-order impacts will not be further quantified in COMMECT project due to their large uncertainties but could be mentioned qualitatively when relevant.

Impact calculation for COMMECT project

The environmental sustainability evaluation of COMMECT solutions will include both first-order (considering the life cycle, LC, of ICT components) and second-order effects (Equation 2).

Eq. 2
$$Impact_{ICT} = Impact_{1st\ order} + Impact_{2nd\ order}$$
$$Impact_{1st\ order} = Impact_{LC,terminal} + Impact_{LC,network} + Impact_{LC,data\ center}$$
$$Impact_{2nd\ order} = Impact_{application,ICT} - Impact_{application,ref}$$

Equation 2 is visualized in the graphic below (Figure 11):

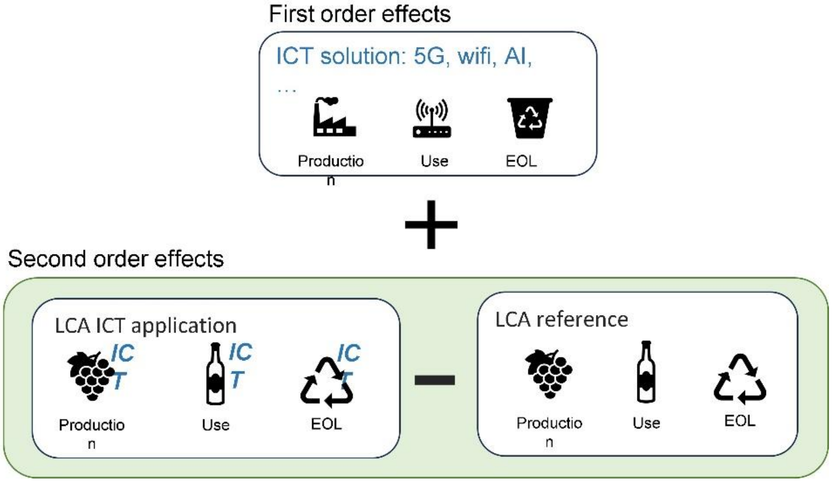


Figure 11 A visualization of the first- and second-order effect calculation

A positive result means the connectivity (digital) solutions generates additional environmental impacts, while a negative result means that connectivity solutions reduce environmental impacts, and thus contributes to avoiding impacts. This is a mathematical convention in sustainability field (e.g., for carbon footprint or any other environmental footprint calculation). Equation 2 can be put in parallel with the one proposed by AIOTI regarding the calculation of total avoided carbon emissions (TAE). The latter, shown in Equation 3 [48] and detailed in Appendix 3, aims at quantifying avoided emissions in vertical/industrial sectors, when applying connectivity / ICT, along the life cycle phases (excluding reuse and recycling):

Eq. 3
$$TAE = T\_CE - (T\_CE_{ICT} + T\_ICT)$$

In Equation 3, the first-order impacts, T_ICT, are summed with the impacts of the application sector with ICT, T_CE_{ICT}. The avoided emissions are calculated from the difference between the impacts of the reference scenario, T_CE, and the sum of T_CE_{ICT} and T_ICT. By rearranging the terms of the equation, we can obtain the opposite of Equation 2, which calculates impacts:

Eq. 4
$$\begin{aligned} TAE &= T\_CE - (T\_CE_{ICT} + T\_ICT) \\ &= Impact_{application,ref} - (Impact_{application,ICT} + Impact_{1st\ order}) \\ &= (Impact_{application,ref} - Impact_{application,ICT}) - Impact_{1st\ order} \\ &= -\,Impact_{ICT} \end{aligned}$$

By taking an example with dummy values, we can observe this equivalency. Let's consider the following climate change impacts for each term:

- $Impact_{1st\ order}$ = T_ICT = 25 kg CO_2 eq./fu (functional unit, e.g., 1 kg of grape)
- $Impact_{application,ref}$ = T_CE = 100 kg CO_2 eq./fu
- $Impact_{application,ICT}$ = T_CE_{ICT} = 40 kg CO_2 eq./fu

With Equation 2, the environmental impacts of the ICT solution would be: 25 + (40 – 100) = 25 – 60 = -35 kg CO_2 eq. for the defined functional unit. With Equation 3, the avoided emissions of the ICT solution would be: 100 – (40 + 25) = 100 – 65 = 35 kg CO_2 eq. Only the sign changes because in the first case, we calculate generated emissions (negative value is a benefit) and in the second case avoided emissions (positive value is a benefit). COMMECT is planning to analyse the environmental impacts using the EF method and following Equation 2.

In an updated version of the AIOTI report [48], Equation 3 has been updated to address the calculation of avoided carbon emissions in industrial sectors when ICT is applied, by focusing on a baseline (industrial) scenario that is supported by an ICT solution and a green enabled (industrial) scenario that apply an advanced ICT solution to reduce carbon emissions in the same industrial scenario. The main difference is that now the baseline scenario may use an ICT solution, which was different than what Equation 3 is covering. Note however, that Equation 3 is still valid for the situation that the baseline scenario does not apply and use an ICT solution.

The details that show the modified Equation 3, are provided in Appendix 3.

The assessment will cover a large range of indicators, including the impact from GHG emissions. This work will contribute to the initiative of AIOTI to quantify GHG emissions reductions in the sector(s) where ICT or connectivity solutions are applied. The evaluation of the environmental sustainability of connectivity solutions will be performed for each LL, depending on the identified use cases. First-order impacts will be quantified based on data regarding ICT components such as antennas, casings, sensors, drones (quantity, specifications, bill of materials, lifetime), their energy consumption during operation (e.g., using a server of X kW for Y hours), and data load (e.g., number of packets transferred and their size or number of bits per given time resolution). The more specific details provided (e.g., energy source, materials name and quantity), the higher quality the evaluation. When relevant, different connectivity solutions providing the same function could be compared, e.g., on a data traffic basis. For second-order impacts, the scope and data requirements will depend on each LL, e.g., the function unit for LL1 can be 1 kg of grape harvested while it can be the 1 kg of olives harvested for LL4. The data collection for the second-order impacts will focus on the changes induced by connectivity solutions (e.g., less irrigation, higher yield). The collected data will be complemented by background data from the ecoinvent database (allocation by cut-off classification, version 3.9.1 or later, if available) [54] and literature data to reflect the upstream and downstream processes. Due to the various sources of uncertainty (potential data gaps, lack of representativeness or data variability), sensitivity and uncertainty analyses will be performed. This work will help identifying the conditions for which connectivity solutions can bring environmental benefits (e.g., calculation of break-even points) and the key parameters to be further investigated and refined.

3.4. On the link between COMMECT results and key indicators for the environmental assessment

While this document has defined and detailed the LCA methodology adopted by COMMECT for the environmental impact assessment, the outputs of the first and second order effects will be presented in future deliverables. Preliminary results will be presented in D5.3 (due at M21, May 2024); more extended results, based on data collected from the five LLs, will be discussed in D5.6 (due at M36). All **16 EF methods defined by the European Commission** [44] (see Table 13) will be evaluated, with a *particular focus on climate change*. It is worth noting that the climate change impact category is the metric used to evaluate the "carbon footprint" of a product or service. The environmental assessment will also consider trade-offs among impact categories (for example, a process may be high in ecotoxicity but low in its climate change impact).

In addition, the results of environmental impact assessment will be integrated into the Decision-making Support tool to guide the end-users towards more sustainable choices, thus contributing to climate change mitigation and increasing the resilience and sustainability of rural communities (COMMECT Objective 4).

4. Definition of environmental assessment scope for the Living Labs

Connectivity solutions are implemented in the COMMECT project to optimize agricultural, horticultural and forestry practices in five LLs. For each Living Lab, several use cases (UCs) are investigated. The environmental impacts of at least five UCs will be performed, ideally at least one per each LL. The following subsections defines the scope (in particular, the functional unit and system boundaries) for evaluating impacts in each LL, based on literature review and use case descriptions (mainly from D1.1 of COMMECT). The required data are also described to facilitate the future collection process. There are a lot of common requirements between LLs. The description of LL1 is thus more detailed than the others, which refer to LL1 for more explanations. Finally, preliminary LCA datasets are modelled based on currently available data (section 4.6).

4.1 Living Lab 1 – Luxembourg – digitalization of viticulture

LL1 focuses on Luxembourg's viticulture, that is an important economic sector for the country, occupying a total area of 1295 hectares. In scientific literature, the environmental evaluation of viticulture and wine production remains quite a recent topic [55]. Although wine is often associated with idyllic landscape images, the cultivation of wine grapes generates environmental impacts due to the removal of native vegetation, soil sterilization, and other agricultural operations [55]. Literature review reveals that viticultural practices show significant impacts in terms of climate change (mainly from energy use and from the supply chain of chemicals used), resources depletion (particularly fossil resources for the supply of diesel, fertilizers or pesticides), eutrophication (fertilizer-related emissions) and (eco-)toxicity (pesticide-related emissions) [56].

The protection and maintenance of vine health is a challenging task. Permanent crops like vines are exposed to the effects of climate change and to the spread of diseases, which require intensive protection and maintenance operations. These challenges will increase with climate change consequences, such as the forecasted increase in temperature and prolonged periods of droughts [57]. The key actions to mitigate the environmental impacts of viticulture are to optimize the number of operations, use more fuel-efficient machinery, greener energy sources, optimize the use of chemicals and water, while maintaining the grape yield.

4.1.1 Definition of the functional unit

The function of the viticulture activities is to provide grapes further use for wine production. The production of wine is excluded from the scope of the COMMECT project. The scenario with or without connectivity should thus be compared for the functional unit (FU) of **the harvesting of 1 kg of grapes in Luxembourg for the period of the project**. Of course, the unit of 1 kg can be changed to another value (e.g., 10 kg or 1 tonne). In literature, the value of 1 kg is the most common one and therefore used here to facilitate further comparison. For the geographical representativeness, the fields on which connectivity solutions would be tested could be further specified. For the temporal representativeness, both scenarios may not happen at the same time, but recent data should be used in both cases. If possible, a multi-year data collection approach is recommended to reduce biases associated with climatic weather conditions which will impact on the final yield and consequently the impacts related to the FU [58].

4.1.2 Definition of the system boundaries

Viticultural operations can be differentiated into the following operations: soil preparation (soil and green cover management), canopy management (pruning, trimming); fertilization;

pesticide spraying; and grape harvesting. These operations involve several input flows, such as the consumption of energy, materials, chemicals, their transport or the use of natural resources, as well as output flows, including emissions of pollutants or waste.

The LL1 intends to investigate two use cases:

- **UC 1.1 In-Field Microclimate and Crop Monitoring in Vineyards**
- **UC 1.2 Digital Twin for Digitalized Management of Vineyards**

The environmental evaluation of UC 1.2 could be complex since it involves many components with effects on the viticulture practices that could be difficult to quantify. For this reason, it was decided to focus on the assessment of UC 1.1 where a digital solution will support the farmer in choosing the ideal diming, dose and treatment for disease control. The aim is to use high-resolution sensor data to make a more spatially differentiated decision on the timing and type of plant protection measures, allowing an optimised use of plant protection products.

To do so, several devices will be implemented: leaf wetness and temperature sensors and additional weather stations to improve the VitiMeteo model forecasts which calculates the risk for downy mildew infestation. The environmental impacts of manufacturing, using and disposing this equipment will be thus included in the system boundaries. The respective data (e.g., mass of materials in each device, energy consumption) will be normalized per kg of harvested grapes (functional unit) to quantify the first-order effects, based on equipment lifetime, yearly consumption, data traffic and yield data.

Besides this, the main effects of UC 1.1 on viticulture are expected on the yield and use of pesticides. The consumption of pesticides and the use of related spraying machines will thus be included in the system boundaries. Besides this, the change of yield could affect all the flows since the use of fertilizers, water or other field works normally depends on the field area. A change of the mass of harvested grapes per m^2 will thus induce a change of these flows/processes, which are also included in the system boundaries. The difference of values per kg of grape harvested for the scenarios with and without (enhanced) connectivity will be used as inputs for the assessment of second-order effects.

The system boundaries are shown in Figure 12, with first-order impacts highlighted in red and second-order impacts in green (difference between the scenarios with and without connectivity solutions). In this case, all agricultural flows could be affected due to the change of yield.

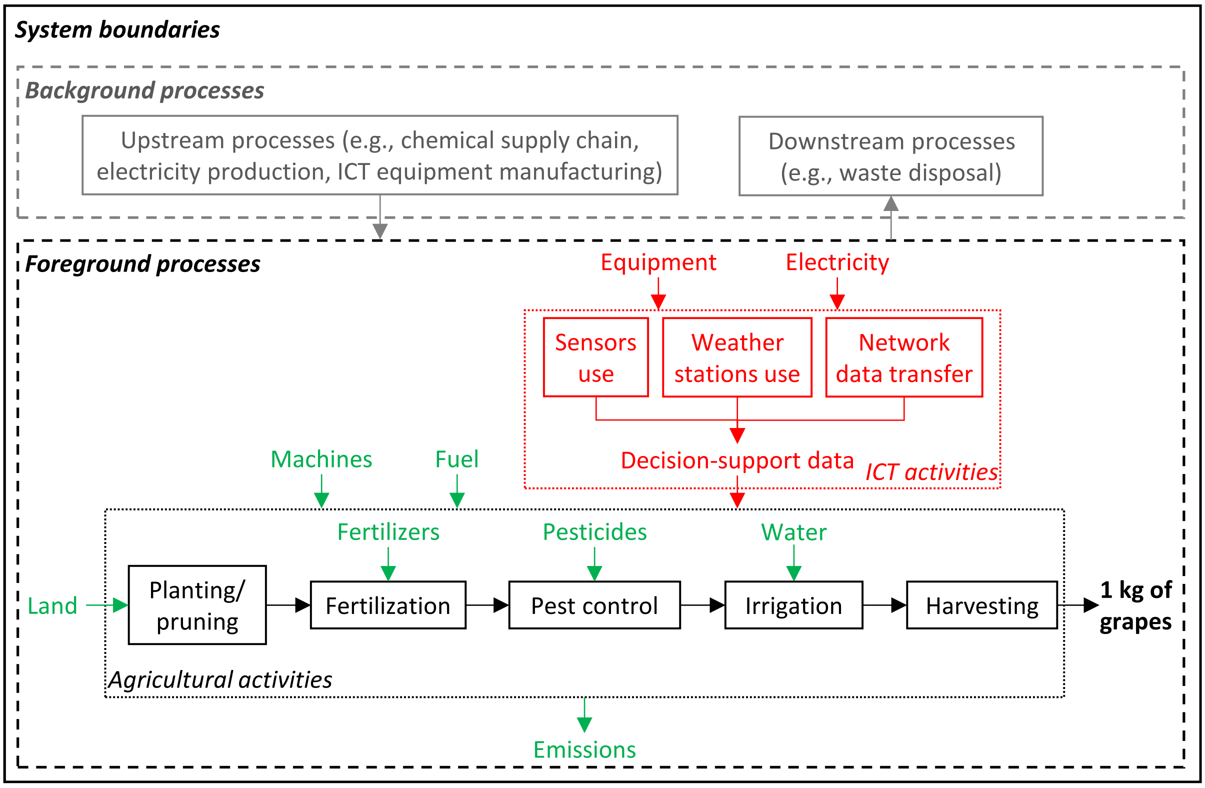


Figure 12. System boundaries for the evaluation of environmental impacts in LL1. Red text represents flows/process for first-order effects, while green text represents flows for second-order effects (the difference between the scenario with connectivity and without connectivity will be used)

4.1.3 Priority data requirements

For first-order effects, the list of all devices used (new or existing), their composition (based on bill of materials) and suppliers will be used to model the manufacturing and transport of ICT equipment. The data will be collected by project partners (in particular the technical specifications and suppliers of all equipment) and be completed with product specification documents, literature or database data. The usage parameters, in terms of data transfer, energy consumption and if relevant maintenance operations (e.g., replacement of spare parts), will be considered to model the operation of the equipment and normalise the manufacturing impacts (based on measurements, equipment specifications or literature). End-of-life impacts will be modelled based on the disposal shares (e.g., between recycling, incineration and landfill) for the different types of included materials/components.

To quantify the second-order impacts, as stated before, the priority is to collect data for the changes induced by the connectivity solutions, which are expected to concern yield and pesticides use. Reference values for viticulture operation should be collected for all flows (e.g., water consumption, fuel consumption for machines) from previous years. This baseline scenario will be more consistent if data from several years and fields can be collected (the specifications of this baseline scenario, e.g., in terms of year, weather conditions, will be used to understand the evaluation reliability). For the changes induced by UC 1.1, the differences between the forecasts with the additional connectivity devices and without it will be analysed to estimate the changes on yield and pesticides use. For example, if the Vitimeteo model forecast based on the new (and closer) station can identify a risk for mildew which was not detected by the old (more distant) station, we can expect that the farmers will apply more pesticides, but this action will increase the associated yield. On the contrary, if it cancels a risk which was badly predicted, the farmers will keep a good yield while decreasing the consumption of pesticides. This quantification exercise will be done with LL1 stakeholders.

The possible ranges of data will be analysed through sensitivity and uncertainty analyses to better support understand the environmental benefits and trade-offs of UC 1.1. The required data for the environmental evaluation are listed in Table 14. The changes of environmental emissions due to the change of pesticides or fertilizers used (e.g., pesticide residues to groundwater, dinitrogen oxide emissions from fertilizer use) will be derived from state-of-the-art equations used in LCA.

Table 14. Key data to be collected to characterize environmental impacts for LL1

<table>
<tr><th colspan="5">First-order effects</th></tr>
<tr><th>Flow / information</th><th>Unit[1]</th><th colspan="2">Value</th><th>Data source / comments</th></tr>
<tr><td colspan="5">Equipment #1</td></tr>
<tr><td>Technical name</td><td colspan="3"></td><td></td></tr>
<tr><td>Brand / Supplier</td><td colspan="3"></td><td></td></tr>
<tr><td>Composition (materials and amount if known)</td><td colspan="3"></td><td></td></tr>
<tr><td>Lifetime</td><td>years</td><td colspan="2"></td><td></td></tr>
<tr><td>Data usage</td><td>GB/year</td><td colspan="2"></td><td></td></tr>
<tr><td>Operating time</td><td>hours/year</td><td colspan="2"></td><td></td></tr>
<tr><td>Power</td><td>kW</td><td colspan="2"></td><td></td></tr>
<tr><td>Electricity consumption</td><td>kWh/year</td><td colspan="2"></td><td></td></tr>
<tr><td>Spare parts replacement (specify component / material)</td><td>kg/year</td><td colspan="2"></td><td></td></tr>
<tr><td colspan="5">Equipment #n (lines to be repeated for each ICT equipment used)</td></tr>
<tr><td>Technical name</td><td colspan="3"></td><td></td></tr>
<tr><td>Brand / Supplier</td><td colspan="3"></td><td></td></tr>
<tr><td>Composition (materials and amount if known)</td><td colspan="3"></td><td></td></tr>
<tr><td>Lifetime</td><td>years</td><td colspan="2"></td><td></td></tr>
<tr><td>Data usage</td><td>GB/year</td><td colspan="2"></td><td></td></tr>
<tr><td>Operating time</td><td>hours/year</td><td colspan="2"></td><td></td></tr>
<tr><td>Power</td><td>kW</td><td colspan="2"></td><td></td></tr>
<tr><td>Electricity consumption</td><td>kWh/year</td><td colspan="2"></td><td></td></tr>
<tr><td>Spare parts replacement (specify component / material)</td><td>kg/year</td><td colspan="2"></td><td></td></tr>
<tr><th colspan="5">Second-order effects</th></tr>
<tr><th>Flow / information</th><th>Unit[1]</th><th>Reference value</th><th>With ICT value</th><th>Data source / comments</th></tr>
<tr><td>Harvested grape (specify type)</td><td>kg/year</td><td></td><td></td><td></td></tr>
<tr><td>Cultivated area</td><td>ha</td><td></td><td></td><td></td></tr>
<tr><td>Yield</td><td>kg/ha</td><td></td><td></td><td></td></tr>
<tr><td>Pesticide consumption (specify chemical name)</td><td>kg/year</td><td></td><td></td><td></td></tr>
<tr><td>Fertilizer consumption (specify chemical name)</td><td>kg/year</td><td></td><td></td><td></td></tr>
<tr><td>Water consumption (specify source)</td><td>m^3/year</td><td></td><td></td><td></td></tr>
<tr><td>Area treated with spraying machine</td><td>ha/year</td><td></td><td></td><td></td></tr>
</table>

Spraying machine fuel consumption (specify type)	L/year			
Area treated with another machine (please specify)	ha/year			
Other machine (please specify) fuel consumption (specify type)	L/year			

[1] Other units may be used depending on data availability (e.g. kWh/GB for ICT equipment electricity consumption, liters for pesticide consumption).

Besides the environmental impacts quantified via LCA methodology, connectivity solutions might have effects on biodiversity not considered in the EF method. Recent methods were developed to better characterize biodiversity impacts in LCA. For example, the consideration of soil organic matter (SOM) content to reflect land use impacts can better reflect the quality of the soil than the current EF indicator, and thus consider the effects of cultivation techniques on such biodiversity indicator [59]. Such evaluation would nevertheless require a more intensive data collection, e.g., the collection of soil samples, and as a result, this is not considered here.

4.2 Living Lab 2 – Norway – Connected Forestry

LL2 focuses on Norway's forestry sector which represents one of the most important economic sectors for employment in the country's rural areas with a combined 12 M m^3 of wood harvest in 2020. Wood is a renewable resource, and it is considered a pillar of the EU bioeconomy strategy [60] as a substitute for more carbon intensive materials in the construction industry, such as steel, concrete, and alloys [61]. Still the ecological credentials of intensifying the use of wood as a substitute material remains debated, particularly the potential loss of ecosystem services due to secondary forests compared to established old growth forests [62] [63].

The environmental profile of wood biomass production is highly influenced by the environmental impacts of forestry operations due to the use of fossil fuels and agrochemicals, inducing direct impacts at site level (combustion of fossil fuel, chemicals spraying) and indirect ones from the supply chain [64] [65]. Key to reduce the environmental impacts from forestry is the reduction of fossil fuels and agrochemicals used through an optimization of operations and a reliance on less impacting machinery.

Forestry operations are broadly subdivided in planting, silviculture, logging, transport and wood processing. Prior to planting and during the silviculture phases, several monitoring, mapping and data logging activities are performed by forest managers to identify protected biotopes, monitor forest health, and identify trees ready for thinning. This data intensive work is currently affected by the often poor digital connectivity of the Norwegian rural areas which can restrict data transfers to once a day, thus limiting work efficiency, quality of data collected, precision of forestry operations, and monitoring ability.

4.2.1 Definition of the functional unit

The function of forestry operations is to produce logs of wood from a forestry plantation to be delivered to a downstream user. The comparison between the reference scenario and the scenario with the ICT solution will be based on the FU of **harvesting of 1 m^3 of round wood under bark in Norway for the period of the project**. This volumetric functional unit is the most employed in forestry LCA studies in scientific literature.

For geographical representativeness, data should be collected from forest areas typical of Norway as the topographic characteristics of the forest highly influence the impact associated with forestry operations (e.g., forestry operations from relatively flat terrain consume less fuel) and from similar wood species as growth characteristics can influence the impacts associated to the functional unit. For the temporal representativeness data should be collected on forestry operations that are occurring over similar time periods. This is because given the relatively long-time span of forestry operations from planting to harvesting, differences in forest management practices over time will generate different data. It is important, therefore, that the reference scenario and the ICT scenario are evaluated on similar forestry management techniques as much as possible.

4.2.2 Definition of the system boundaries

Forestry operations can be divided into four main subsystems: seedling production, silviculture operations, logging and forwarding operations, and hauling. For the scope of the COMMECT project, only silviculture and logging/forwarding operations will be considered. Silviculture operations can be further distinguished between planting, care, thinning, and fertilization.

Three use cases have been identified for application of connectivity solutions in LL2:

- **UC 2.1 Remote operational support from expert for forest machine operator**
- **UC 2.2 Complex situational awareness services in the forest**
- **UC 2.3 Digital decision support for the forest machine operators**

The UC 2.2 is focusing on specific emergency situations to improve the workers safety and prevention of outbreak of the emergency situations, such as forest fires, landslides, floods or other accidents. Safety aspects are normally not included in LCA, as it focuses on average operating conditions. The prevention of out-break of forest fires could prevent realisation of significant amount of negative environmental impact, but would be difficult to assess. This use case is thus excluded from the environmental evaluation.

Both UC 2.1 and UC 2.3 could improve the forestry operations, by providing support to the operator to better select trees, repair machines and optimise their use. In addition, the deployment of digital support in UC 2.1 could optimise the transport of specialists or repairmen to the field. The relevance of these use cases nevertheless needs to be further evaluated based on a better understanding of the associated consequences and the feasibility to quantify them.

The additional connectivity devices will include VR, sensors, digital cameras, UAVs, and 5G antennas. The manufacturing, use and disposal of this equipment will be modelled for the assessment (first-order impacts). As for LL1, the associated data will be normalized to the reference flow, i.e., 1 m^3 of wood, based on equipment lifetime, yearly consumption, data traffic and yield data.

Regarding second-order effects, the main expected changes of UC 2.1 and UC 2.3 concern the use of the machines (associated fuel consumption and emissions), the generation of wood waste. Further discussion with LL2 stakeholders will be needed to confirm this and determine the quantification method for these flows.

The system boundaries are shown in Figure 13. Some forestry flows are currently not expected to be affected by UC 2.1 and UC 2.3 (pesticides and fertilizers consumption), although this should be further confirmed. These flows are thus shown in black and not in green, as for second-order impacts. Their inclusion could still be relevant to understand the impacts of use cases on the overall forestry impacts.

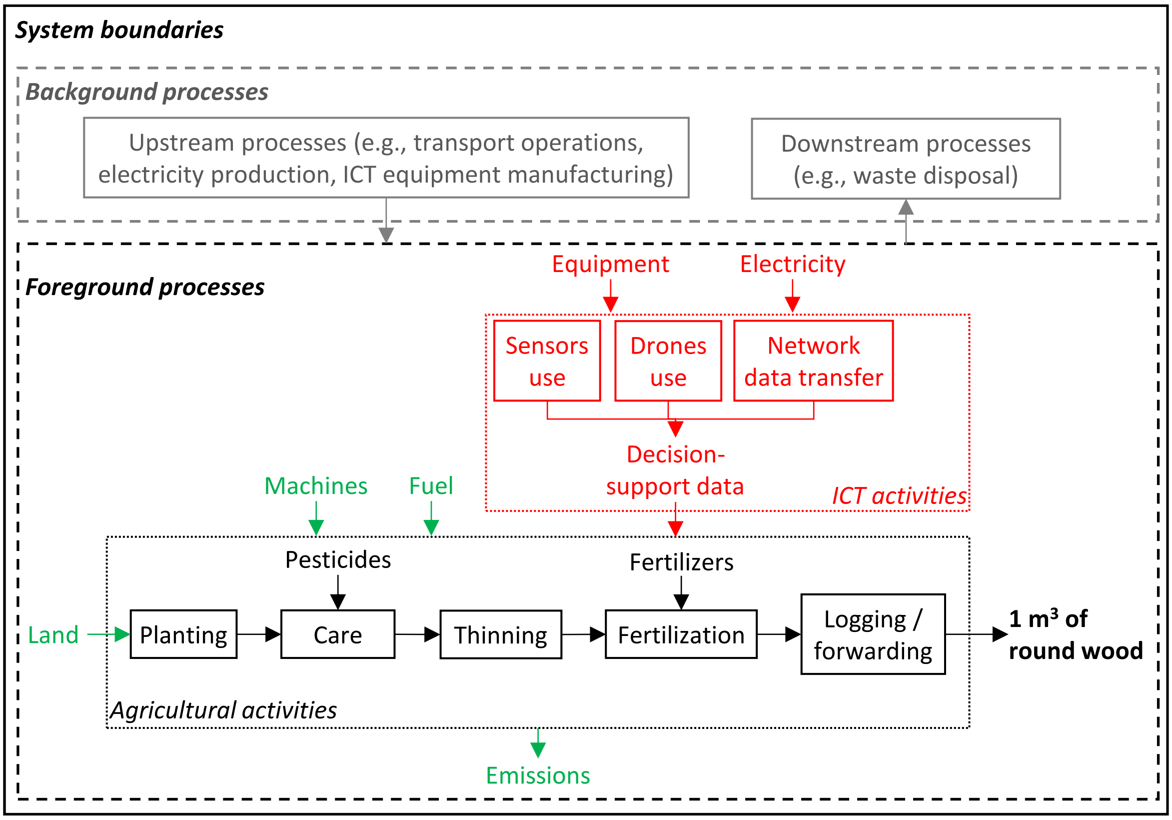


Figure 13. System boundaries for the evaluation of environmental impacts in LL2. Red text represents flows/process for first-order effects, while green text represents flows for second-order effects (the difference between the scenario with connectivity and without connectivity will be used)

4.2.3 Priority data requirements

Evaluating first-order impacts of LL2 requires the same type of data requests as mentioned in LL1 i.e., the list of equipment and for each of them their brand, supplier, composition (type and amount of materials), lifetime, data usage, energy consumption and maintenance.

Regarding second-order impacts, all the input and output flows of forestry operations would need to be quantified, focusing on the ones affected by COMMECT use cases. The later should concern the fuel consumption of machines and the distance travelled by workers. The potential effect on yield could be also investigated. The method to estimate the changes induced by UC 2.1 and UC 2.3 still need to be determined.

As in LL1, the best is to collect data representative for the use cases over a long period. The variability of data could be analysed to understand the effects on LCA results. The required data for the environmental evaluation are listed in Table 15.

Table 15. Key data to be collected to characterize environmental impacts for LL2

First-order effects				
Flow / information	**Unit[1]**	**Value**		**Data source / comments**
Equipment #1				
Technical name				
Brand / Supplier				
Composition (materials and amount if known)				
Lifetime	years			
Data usage (specify type)	GB/year			
Operating time	hours/year			
Power	kW			
Electricity consumption	kWh/year			
Spare parts replacement (specify component / material)	kg/year			
Equipment #n (lines to be repeated for each ICT equipment used)				
Technical name				
Brand / Supplier				
Composition (materials and amount if known)				
Lifetime	years			
Data usage	GB/year			
Operating time	hours/year			
Power	kW			
Electricity consumption	kWh/year			
Spare parts replacement (specify component / material)	kg/year			
Second-order effects				
Flow / information	**Unit[1]**	**Reference value**	**With ICT value**	**Data source / comments**
Harvested wood (specify type)	m^3/year			
Cultivated area	ha			
Repairmen or machine specialists travelling onsite (specify transport type)	km/year			
Pesticide consumption (specify chemical name)	kg/year			
Fertilizer consumption (specify chemical name)	kg/year			
Area treated with machine (please specify) [2]	ha/year			
Machine (please specify) fuel consumption (specify type) [2]	L/year			

[1] Other units may be used depending on data availability (e.g. kWh/GB for ICT equipment electricity consumption, liters for pesticide consumption).
[2] These cells could be copy-pasted for the number of forestry machines which are affected by connectivity solutions (e.g., machines for planting, thinning, harvesting).

4.3 Living Lab 3 – Denmark – Connected Livestock Transport

LL3 focuses on the transport of piglets from Denmark, which represented 14.5 million transported piglets to countries in Europe alone in 2018. The Padborg Transport Center located at the Danish border to Germany, sees around 3000 truck visits per day and handles approximately 60% of all live animal transport to and from Denmark. It also handles the washing, disinfection, veterinary inspection, and control for disease for 92% of the livestock trucks and trailers in Denmark.

The transport sector represents significant environmental impacts, particularly climate change (about 25 % of GHG emissions in Europe[1]). Regarding freight transport, trucks represent the most impacting mode. It is thus important to mitigate these impacts. Livestock production represents about 10% of GHG emission in EU [66]. Any avoided waste on the supply chain can generate significant environmental benefits, which could be the case by increasing the health of pigs during transportation process.

The animal welfare is conventionally not considered in LCA. A new framework was nevertheless developed by [67]. Criteria included animal life quality (space allowance for pigs), slaughter age, the number of animals needed to fulfil 1Mcal (or other functional unit), and the level of sentience of the animal. However, the framework by Scherrer et al. [67] focuses on the lifecycle of an animal (birth to slaughter) and not the specific steps of animal production and transport, thus hampering the applicability for this LL assessment.

4.3.1 Definition of the functional unit

The function of LL3 is to transport piglets. For freight transport processes, the common unit in LCA is tonne.kilometre (tkm), allocating impacts depending on the transported mass and travelled distance. The functional unit for LL3 will thus be **1 tkm of piglets transported from Denmark to other European countries for the period of the project**. Similar types of pigs would need to be considered between the reference scenario and the one with the ICT solution. For the geographical representativeness, the restriction of the functional unit to specific routes could be envisioned depending on the relevance and feasibility (e.g., focus on the transport from Denmark to South Germany). For the temporal representativeness, both scenarios may not happen at the same time, but recent data should be used in both cases.

4.3.2 Definition of the system boundaries

This LL aims to introduce connectivity solutions to better monitor and trace pig welfare via sensors and cameras throughout the loading, transport, and unloading phases, as well as being able to improve transport operations (e.g., reducing delays, increase turnover, optimize routes travelled, optimize documentation), via the following three use cases:

- **UC 3.1 Monitoring of Livestock Transport along Rural Routes**
- UC 3.2 License plate recognition
- UC 3.3 Monitoring of livestock loading/unloading processes
- UC 3.4 Data- and AI-driven next generation livestock transport

After discussing with LL3 partners, the most relevant use case which could generate environmental impacts and for which data could be derived is the UC 3.1, focusing on the use of ICT to optimize transport.

[1] https://climate.ec.europa.eu/eu-action/transport/overview_en

The UC 3.1 will imply the use of several connectivity solution equipment: sensors, navigation system and network system. As for previous LLs, the lifetime of these devices would need to be modelled and normalized to 1 tkm of transported pigs to evaluate first-order impacts.

The second-order impacts include the effects on the transport process (fuel consumption and related emissions) for the outward and return travels. The loading and unloading phases are not expected to influence the LCA results. In addition, considering a stable amount of pigs transported, the farming impacts related to pigs production are not expected to affect second-order impacts.

The system boundaries are shown in Figure 14. Besides fuel-related data, the inclusion of impacts related to pigs' production or loading/unloading phases could still be performed to understand the impacts of the use case to the overall livestock supply chain.

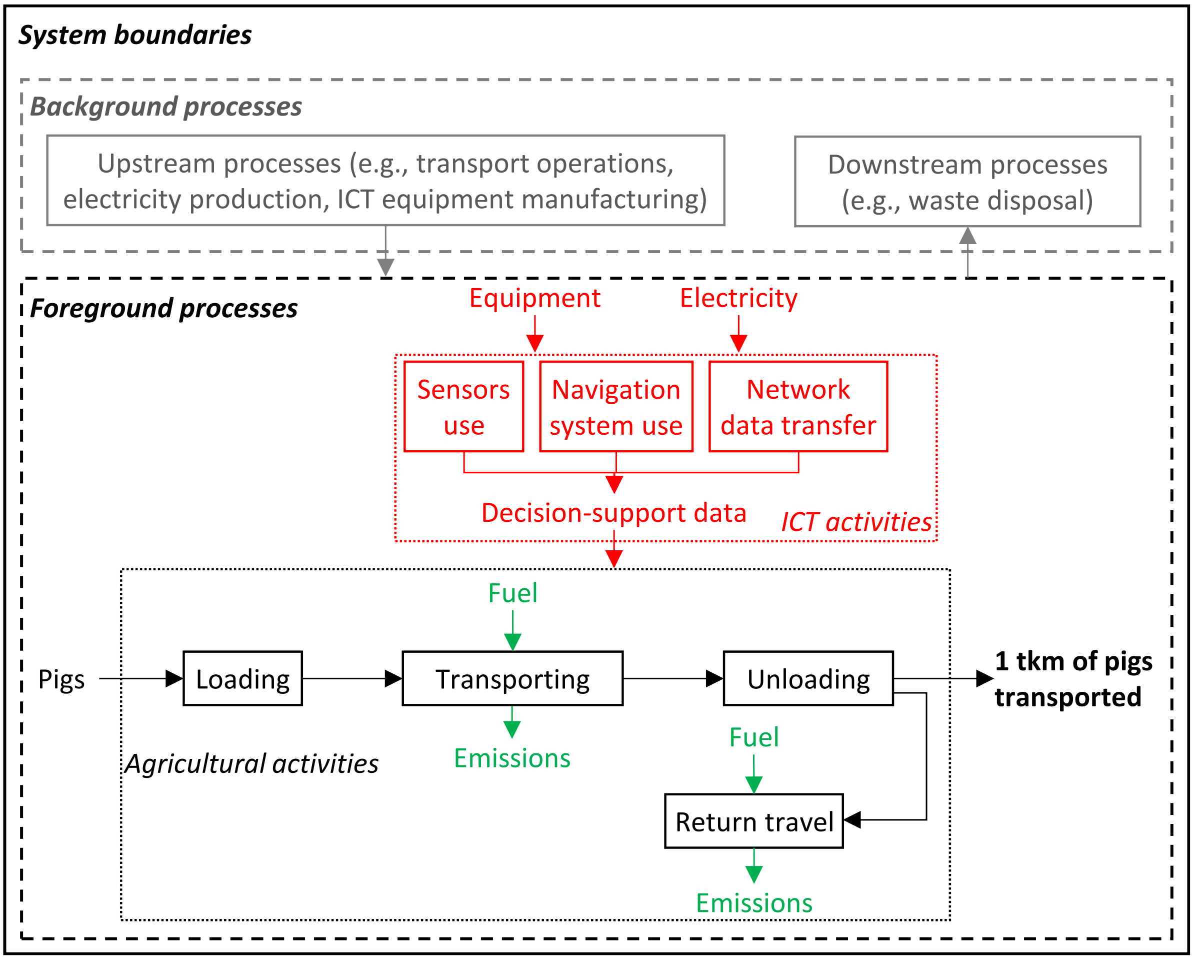


Figure 14. System boundaries for the evaluation of environmental impacts in LL3. Red text represents flows/process for first-order effects, while green text represents flows for second-order effects (the difference between the scenario with connectivity and without connectivity will be used)

4.3.3 Priority data requirements

The same connectivity-related data than for previous LLs are required to quantify the first-order impacts.

Regarding the second-order impacts, a focus on specific routes could be performed to facilitate the data collection process. The quantification of travelled distance and associated fuel consumption for worst, average and best conditions could be used to estimate the possible margin of improvement thanks to connectivity solutions. Data regarding the amount of transported pigs would still be needed to normalize the impacts to the functional unit and potentially to compare the transport benefits to the overall livestock production impacts.

The required data for the environmental evaluation are listed in Table 16.

Table 16. Key data to be collected to characterize environmental impacts for LL3

First-order effects				
Flow / information	**Unit[1]**	**Value**		**Data source / comments**
Equipment #1				
Technical name				
Brand / Supplier				
Composition (materials and amount if known)				
Lifetime	years			
Data usage	GB/year			
Operating time	hours/year			
Power	kW			
Electricity consumption	kWh/year			
Spare parts replacement (specify component / material)	kg/year			
Equipment #n (lines to be repeated for each ICT equipment used)				
Technical name				
Brand / Supplier				
Composition (materials and amount if known)				
Lifetime	years			
Data usage	GB/year			
Operating time	hours/year			
Power	kW			
Electricity consumption	kWh/year			
Spare parts replacement (specify component / material)	kg/year			
Second-order effects				
Flow / information	**Unit[1]**	**Reference value**	**With ICT value**	**Data source / comments**
Truck type				
Route details[2] (point of departure and arrival)				
Pigs transported (specify type)	kg/route			
Fuel consumption (specify type)	L/route			
Travelled distance	km/route			

[1] Other units may be used depending on data availability (e.g. kWh/GB for ICT equipment electricity consumption, kg for fuel consumption).
[2] The data can be collected for several routes. In that case, the required data for second-order effects need to be provided for each route (copy-paste the lines).

4.4 Living Lab 4 – Turkey – Smart Olive tree farming

LL4 refers to olive groves in Turkey's rural areas. Olive production in Turkey is based on traditional methods, characterized by low density olive groves, minimal use of mechanization, and uniform and non-selective application of inputs such as fertilizers, pesticides, and water over the entire cultivation area [68] [69]. This type of farming practice is characterized by low productivity and consequently low profitability while having substantial environmental and social costs [70].

Olive oil production, despite being a prominent agricultural sector in the Mediterranean region, lacks comprehensive studies on its environmental effects compared to other agricultural systems [71]. Traditional olive farming practices contribute to soil erosion, desertification (especially in hilly areas), and negative impacts on biodiversity [72]. The cultivation of olives consumes significant resources and generates emissions to the environment, leading to substantial environmental degradation. During the farming phase, major inputs include fuels, electricity, water, and agrochemical products such as fertilizers, pesticides, and herbicides. The extensive use of chemical products poses health risks to workers, as they have been associated with severe health conditions and human diseases [70]. Additionally, the milling phase (olive oil production) results in hazardous waste residuals from the olive crushing process [71]. To mitigate the environmental impacts of olive farming, prioritizing optimization of fertilization is crucial. Furthermore, adopting sustainable agricultural practices such as no-tillage or reduced tillage, biological pest control, mechanical weeding, and utilizing renewable energy for irrigation systems can contribute to alleviating the environmental burdens resulting from olive farming [73].

4.4.1 Definition of the functional unit

Given that the objective of LL4 is to improvement the management and yield of olive farming, the functional unit should be defined as **1 kg of olives harvested in Turkey for the period of the project**. The further transformation of olives into oil is not in the scope of the project. For geographical representativeness, the analysis should be conducted on geographically similar plots of land and same cultivar, and for temporal representativeness, the evaluation of the potential effects of connectivity solutions should be assessed considering the natural alternation of olive yields and therefore apply a multi-year data collection approach, if feasible, and on groves of a similar age [70].

4.4.2 Definition of the system boundaries

Olive orchards present different life cycle stages: planting, growing phase, production phase, and end of life. The production phase, i.e., olive farming, includes steps such as irrigation, pruning, fertilization, soil management, pest/weed control and harvesting.

LL4 aims to improve these operations via two use cases:

- **UC 4.1 Microclimate Monitoring for Early Disease and Pest Detection**
- **UC4.2 Monitoring of pest insect traps**

The UC 4.1 is similar to the UC 1.1 in Luxembourg, i.e., the implementation of weather station sensors will provide microclimate data to the farmers to facilitate the detection of diseases and olive fly, and thus improve the pathogens and pest control. The first-order impacts will thus include the life cycle of the ICT devices (weather stations, network system) while the second-order impacts will consider the effects on pesticides consumption and on yield (affecting all the other flows due to the normalization per kg of olives, as for LL1).

The UC 4.2 is also relevant for the environmental evaluation. This use case will imply the deployment of digital traps to facilitate the detection of olive flies and thus also improve pest management. As for UC 4.1, the key affected flows are the consumption of pesticides and the yield.

The system boundaries are shown in Figure 15, which highlights that all agricultural flows could be affected by the connectivity solutions (in green colour).

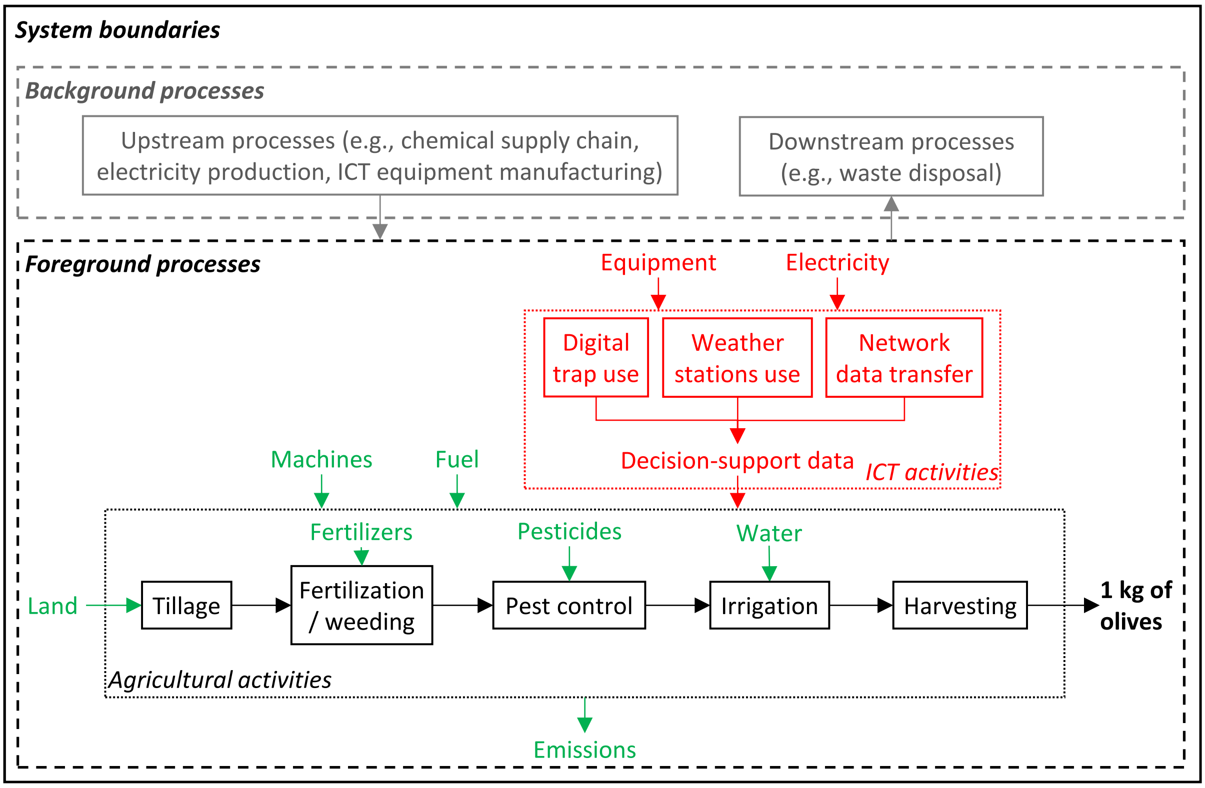


Figure 15. System boundaries for the evaluation of environmental impacts in LL4. Red text represents flows/process for first-order effects, while green text represents flows for second-order effects (the difference between the scenario with connectivity and without connectivity will be used).

4.4.3 Priority data requirements

Regarding first-order impacts, the same data than for previous LLs need to be collected for each used device.

As for LL1, the key data to evaluate second-order impacts are the changes of yield and pesticides consumption induced by the new connectivity solutions. If the yield is affected, all other flows, expressed per kg of harvested olives, need also to be modified (if constant per cultivated area). Reference values for all agricultural operations (consumption of fuel, water, pesticides, etc.) could be collected for previous years by LL4 partners. The changes induced by UC 4.1 and UC 4.2 could be derived from the decision-support data provided by the connectivity devices and the knowledge of LL4 stakeholders. Realistic ranges of data could be exploited to investigate the conditions for which ICT solutions would generate environmental benefits.

The required data for the environmental evaluation are listed in Table 17.

Table 17. Key data to be collected to characterize environmental impacts for LL4

First-order effects

Flow / information	**Unit[1]**	**Value**		**Data source / comments**
Equipment #1				
Technical name				
Brand / Supplier				
Composition (materials and amount if known)				
Lifetime	years			
Data usage	GB/year			
Operating time	hours/year			
Power	kW			
Electricity consumption	kWh/year			
Spare parts replacement (specify component / material)	kg/year			
Equipment #n (lines to be repeated for each ICT equipment used)				
Technical name				
Brand / Supplier				
Composition (materials and amount if known)				
Lifetime	years			
Data usage	GB/year			
Operating time	hours/year			
Power	kW			
Electricity consumption	kWh/year			
Spare parts replacement (specify component / material)	kg/year			
Second-order effects				
Flow / information	**Unit[1]**	**Reference value**	**With ICT value**	**Data source / comments**
Harvested olives (specify type)	kg/year			
Cultivated area	ha			
Yield	kg/ha			
Pesticide consumption (specify chemical name)	kg/year			
Fertilizer consumption (specify chemical name)	kg/year			
Water consumption (specify source)	m^3/year			
Area treated with spraying machine	ha/year			
Spraying machine fuel consumption (specify type)	L/year			
Area treated with another machine (please specify)	ha/year			
Other machine (please specify) fuel consumption (specify type)	L/year (or kWh/year)			

[1] Other units may be used depending on data availability (e.g. kWh/GB for ICT equipment electricity consumption, liters for pesticide consumption).

4.5 Living Lab 5 – Serbia – Sustainable Agriculture

The Living Lab in Gospodjinci concerns two nature reserves (Mrtva Tisa and Jegrička) and an area called Pearl Island, which is used by local farmers for agriculture. Currently, the area is very rural without electricity and accessed mainly by dirt roads. Due to the climate change, there is an increased need for better irrigation as summers become drier. The COMMECT project hopes to digitize some of the farming practices while also monitoring for pollution and preserving biodiversity. The intended outcomes of this LL include reduced pesticide use and optimized irrigation in agricultural areas, improving network connectivity to facilitate introduction of digital solutions, and ensuring better monitoring of environmental conditions leading to the better protection and preservation of the nature reserves.

When looking at the environmental impacts of various activities in a specific region, some scholars worked on the definition and implementation of the so-called territorial LCA. For the latter, the impacts can be measured in two ways: 1) by assessing a certain activity or supply chain in the area or 2) by assessing all consumption and production activities in the area [74]. The first type relates to the conventional application of LCA, but only partial evaluation of the territory impacts would be evaluated. In the second case, the entire system is studied but it raises challenges regarding the definition of the functional unit. To aggregate all the functions of the territory, economic or surface-related indicators can be used. Such evaluation also requires including all production and consumption processes, as the territory is evaluated as one unit each under a different lens (economic, environmental, social) rather than a specific function.

Besides the agricultural activities, the LL includes a nature park and its monitoring and protection. LCA methodology has been applied to assess nature-based solutions. The literature review by Larrey-Lasalle et al. [75] remarked that ecological restoration sites focusing on soil often used a functional unit related to area (e.g. “area of mulched land”) and sites focusing on pollutant removal used different functional units (e.g., yearly mass of biomass, of cultivated area or of treated volume of pollutant) depending on the scope of the study. Recreational areas (e.g., parks) evaluated the impacts based on the surface area. For multi-functional area with nature-based solutions, Babí Almenar et al. [76] state that the area and lifetime are often used as functional units for LCA evaluation.

4.5.1 Definition of the functional unit

As highlighted below, this LL can have several functions (different farms cultivating different crops, provision of a natural-protected area). Following the trends found in Larrey-Lasalle et al. [75], using the surface area as reference unit could be appropriate to consider these multiple activities. However, after discussing with LL5 partners, a focus on agricultural activities seems the most relevant and feasible for an environmental assessment. In that case, the functional unit refers to the mass of crops produced (several crops could be investigated, e.g., corn, wheat, sunflower, soybean)**.** The functional unit is thus **the harvesting of 1 kg of crops in Serbia for the period of the project**. The effects on several types of crops could be cumulated to understand the total impacts for the region.

The assessment for the scenarios with and without connectivity should be within the same time horizon (e.g., 1 month, 1 year, …), season, and geographical area.

Due to the diversity and interconnectedness of natural areas, the influence of the connectivity solution on ecosystem services (e.g., recreational services, biodiversity protection) will not be quantified in the LCA evaluation but will be discussed qualitatively if relevant.

4.5.2 Definition of the system boundaries

This LL contains four UCs:

- UC 5.1 Creation of a shared rural infrastructure
- UC 5.2 Securing crops and equipment
- UC 5.3 Shared environmental monitoring platform
- **UC 5.4 Shared digital agricultural platform**

- UC 5.5 Shared community platform

Based on exchanges with LL5 partners, the most relevant use case for the environmental evaluation is the UC 5.4 which has a direct link with the improvement of agricultural practices.

For UC 5.4, ICT devices installed in UC 5.1, i.e., sensors and network system, will be used to feed the agroNET platform. The latter will provide real-time data and insights to the farmers to better manage their fields. The life cycle of the ICT equipment will be modelled and allocated to the data used by farmers and normalized to the functional unit (1 kg of crops) to evaluate first-order impacts.

The agroNET platform intends to mainly influence the use of pesticides, water and potentially the soil quality (mitigating leaching effects). The changes on yield could also be investigated. As for LL1 and LL4, all input and output flows for the agricultural activities are thus included in the study to assess second-order impacts.

The system boundaries for LL5 are shown in Figure 16.

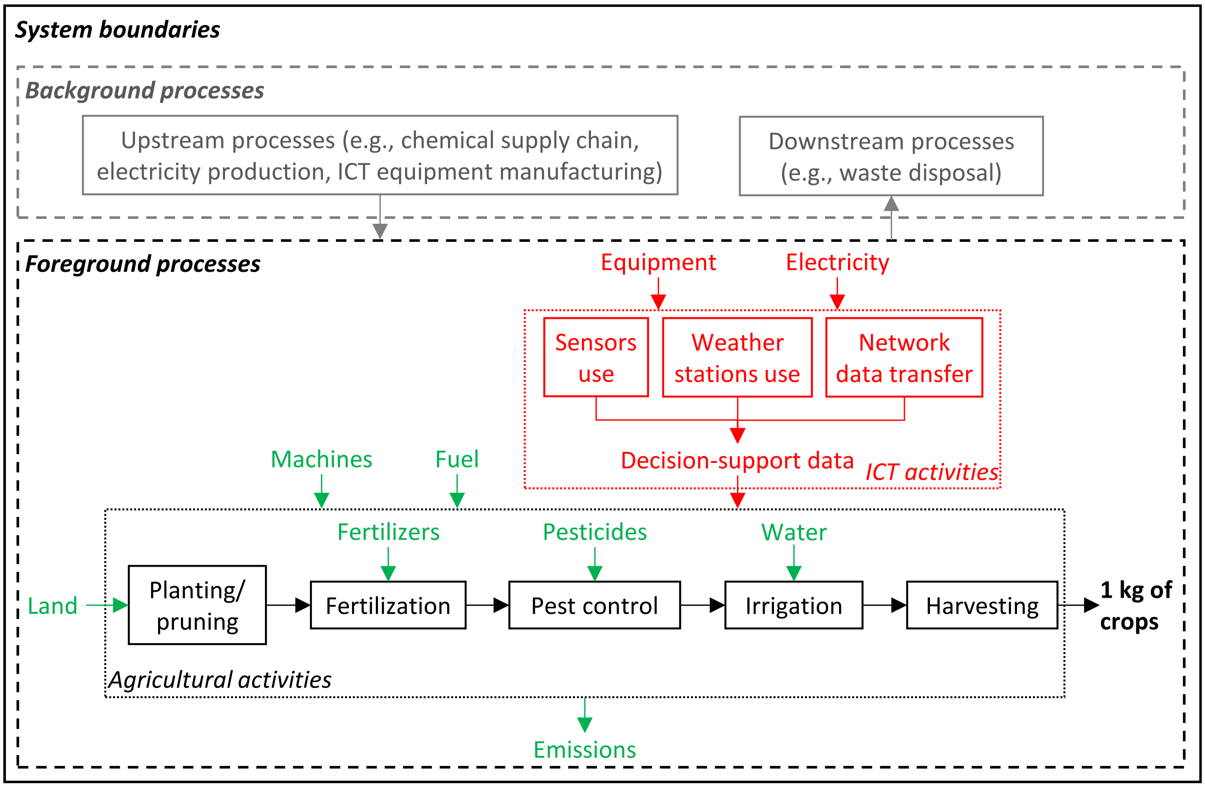


Figure 16. System boundaries for the evaluation of environmental impacts in LL5. Red text represents flows/process for first-order effects, while green text represents flows for second-order effects (the difference between the scenario with connectivity and without connectivity will be used).

4.5.3 Priority data requirements

The same data for ICT devices as for the other LLs are required to quantify first-order impacts.

The data requirements for the second-order impacts are similar to those of LL1 and LL4. For each studied farm (the number of farms and associated crops should still be determined depending on data availability), agricultural data (e.g., consumption of pesticides, fertilizers, yield) from previous years will be collected to define the reference scenario. The changes induced by the better access to real-live data will need to be estimated from the results obtained with the agroNET platform and the knowledge of LL5 stakeholders.

The required data for the environmental evaluation are listed in Table 18, where second-order data would need to be collected for each studied farm.

Table 18. Key data to be collected to characterize environmental impacts for LL5

First-order effects				
Flow / information	**Unit[1]**	**Value**		**Data source / comments**
Equipment #1				
Technical name				
Brand / Supplier				
Composition (materials and amount if known)				
Lifetime	years			
Data usage	GB/year			
Operating time	hours/year			
Power	kW			
Electricity consumption	kWh/year			
Spare parts replacement (specify component / material)	kg/year			
Equipment #n (lines to be repeated for each ICT equipment used)				
Technical name				
Brand / Supplier				
Composition (materials and amount if known)				
Lifetime	years			
Data usage	GB/year			
Operating time	hours/year			
Power	kW			
Electricity consumption	kWh/year			
Spare parts replacement (specify component / material)	kg/year			
Second-order effects				
Flow / information	**Unit[1]**	**Reference value**	**With ICT value**	**Data source / comments**
Harvested crops[2] (specify type)	kg/year			
Cultivated area	ha			
Yield	kg/ha			
Pesticide consumption (specify chemical name)	kg/year			
Fertilizer consumption (specify chemical name)	kg/year			
Water consumption (specify source)	m^3/year			
Area treated with spraying machine	ha/year			
Spraying machine fuel consumption (specify type)	L/year			
Area treated with another machine (please specify)	ha/year			

Other machine (please specify) fuel consumption (specify type)	L/year			

[1]Other units may be used depending on data availability (e.g. kWh/GB for ICT equipment electricity consumption, liters for pesticide consumption).

[2]The data could be collected for each type of crops potentially affected by connectivity solutions deployment. In this case, the required data for second-order effects need to be provided for each crop (copy-paste the lines).

4.6 Life cycle inventory (LCI) and energy intensity for connectivity equipment and networks

The framework depicted in Table 19 is used to make an organized inventory as comprehensive as possible of all the connectivity-related infrastructures, equipment and networks that might be deployed in the five living labs. The following table and paragraphs provide a preliminary/generic of LCI information for such connectivity solutions based on literature. Then, these data sets will be fine-tuned, completed, and specified with the actual equipment used in each of the five living labs, when available.

Table 19. ICT-related infrastructures, equipment and networks

Sub-system	Definition	Examples of equipment
Data centers	Telecommunications facility for data computing, data connectivity platforms, and data storage	Servers, storage equipment, power supply units, cooling equipment, air conditioning units
Data transmission	High-bandwidth cable infrastructure, supporting Internet infrastructure and connecting regions	Terrestrial and (sub)marine communication: optic fibre cables, amplifiers, copper cables Wireless communication: Wi-Fi, 3G, 4G, 5G, telecom satellites Routers, DNS servers
Core network	Internet Service Provider (ISP) equipment forming regional, national, and global networks	Switches, routers, file servers, cabling systems Evolved Packet Core (EPC), 5G Core (5GC)
Access network (cell site or gateway)	Structures where communication equipment is placed, connecting users to the ISP	Base station (e.g., eNodeB), base band unit, radio frequency unit, power bank, integrated battery cabinet, antenna towers
Customer premise equipment (CPE)	Equipment kept at the customer's physical location rather than on the service provider's premises	Equipment used to access the Internet, e.g., routers, modems, set-top boxes
End-user devices	Any piece of electronic / connected equipment, for a particular purpose and used by a given person	Smartphones, computers, vehicles, robots, drones, IoT devices, etc.

Regarding the energy intensity of the wireless networks used in the different LLs, an assessment on the energy-efficiency of LoRaWAN and LPWAN by Sherazi et al. (2021) estimates that LoRaWAN consumes maximum 85 J/day when nodes are sensing at 1-minute intervals. As the sensing time goes down, so does the energy consumption (every five minutes is nearer to 16 J/day). LoRaWAN is a type of LPWAN (Low Power Wide Area Networks) that requires sensor nodes and gateways to transmit data. The sensor nodes are often powered by batteries. Sherazi et al. [77] calculate that battery life can range from 8 years (optimistic) for a 13 decibel-milliwatts (dBm) power configuration to <2 years (pessimistic) for a 20 dBm configuration. These values also depend on how frequently the sensor nodes are sending data (e.g., every minute versus every five minutes). They found that sending data every five minutes resulted in a per LoRa node savings of 3.22 kg CO_2/kWh.

Gawron et al. [78] cite an Australian publication for the energy intensity to transmit data over 4G LTE networks of 1.25 MJ/GB and multiplied this with the average GHG emissions of the

US electricity grid mix to find the total emissions as a result of transmitting data. The value 1.25 MJ/GB includes the power consumption of all base stations, data centers, and networks needed to transfer the data.

For Living Labs that will require drone surveillance (such as the Norwegian LL), there are one a few studies that investigate their environmental impact and their energy consumption. One such study, from Sacco et al. [79], found that using a drone to assess crop health covered 5 hectares/hour, which was one drone flight, and this used 177.6 Wh (8000 mAh at 22 V). When calculating the energy requirements of remote sensing techniques, they found that the drone collected 1.5 GB/ha; orthophotos (a scale-corrected projection image) collected 300MB/ha which also required 0.5hr/ha of processing time. This data would then need to be transferred through the LoRa network.

The LCIs were developed on the inputs provided from each LL. Finding the material inputs for each item required extensive online searches, references in literature, and occasionally cross-checking with datasets from the ecoinvent (version 3.9.1 (2022)) database [54]).

To obtain a useful contribution analysis, which allows LCA practitioners to see the most impactful aspects of a process, some connectivity equipment was broken down into sub-parts (e.g., base station broken down into baseband unit, frame, antenna, pole (if needed)). The Appendix 4 provides an example of how the LCI is composed for a LoRa gateway and its inclusion in LL1. The LCI focuses on the production phase of the ICT equipment. The LCI database will be continuously updated as new LCI data and new information from the LLs is collected.

Table 20, below, summarizes the LCI components pertaining to the different categories of ICT infrastructure for each living lab and the data transmission network that will be used. Sources for the data have been provided in the table. Notably, the core network and data centers are not well considered here. If data passes through several routers (located in several data centers), it becomes more difficult to track. Thus, generalized data related to the energy consumption per data size (e.g., kWh/GB) will be used here to estimate the impact of data transfer. In the same vein, only the energy required for data transmission to the satellite (GEO or LEO constellations) will be considered. This is because we do not know the share of use that the LL data will require of each satellite to calculate the environmental impact.

Table 20. Preliminary LCI for the connectivity equipment used in the living labs

Category of connectivity solution	Specific connectivity equipment (and infrastructure)	LCI data (BoM, energy intensity)	Sources (references)	LL1	LL2	LL3	LL4	LL5
End-user devices	Camera	Peer-reviewed LCI	[80]				X	
	PTZ camera	BoM	[81]					X
	Multispectral and IR cameras	In progress	In progress	X				
	Leaf wetness sensor	BoM	[82]	X				
	Soil moisture sensor	In progress	In progress	X			X	
	Air quality sensor	In progress	In progress					X
	Insect trap	In progress	Confidential				X	
	Data logger	In progress	In progress	X				X
	Productivity tracker (GPS/GNSS)	In progress	Confidential			X	X	X
	Weather station	BoM	Confidential	X			X	
	Drone	Peer-reviewed LCI	[83] [84] [79]		X			
	SSD	EPD	[85]					X
	Compact solar panel (to power weather station)	In progress	In progress	X			X	
Customer premise equipment	Modem	LCI dataset	Ecoinvent v3.9.1			X		
	Router	LCI dataset	Ecoinvent v3.9.1					X

Access network	Micro base station	Peer-reviewed LCI	[86]				X	
	Gateway	White paper	[87]	X				
	Baseband unit	White paper	[88]					
	Remote radio unit	White paper	[88]					
	Single board computer	In progress	In progress			X		
	5G antenna	White paper, Peer-reviewed LCI	[87][89]					
Core network	Switch	In progress	In progress					X
Data transmission	3G/4G/4.5G/5G	Peer-reviewed paper, white paper	[78] [88] [90] [91]	3G/4G		5G	4.5G	4G
	LoRaWAN	Peer-reviewed paper	[77]	X				X
	Satellite constellation	In progress (data transmission only)	In progress			X		
	Electricity	LCI dataset, peer-reviewed papers	Ecoinvent v3.9.1, [86] [92]	X	X	X	X	X
	Batteries	LCI dataset	Ecoinvent v3.9.1		X	X	X	
Data centers								

5. Link between the socio-economic and environmental impact assessment and the DST in COMMECT

All the data that will be collected using the frameworks described in the previous chapters, will be input for the Decision-Making Support Tool (DST), which is being developed in parallel in Task 3.4. This DST will help various groups of users (e.g., farmers, municipalities, community members, companies) to make the optimal decision when it comes to choosing a technological setup which fulfils their needs, helping them to take the initial investment as well as operational decisions.

The different connectivity solutions in the use cases each have their impact in terms of business development and socio-economic and environmental impact. The DST should be able to provide insights or recommendations based on the specific characteristics in which the connectivity solutions will be applied: therefore, the DST should interpret (using the frameworks presented in the previous chapters) what impact can be expected (and why this is the case). The DST therefore will 'translate' questions or requirements that users may have into insights or even actional recommendations to users on the deployment of connectivity solutions in rural areas. Figure 17 below shows the working logic of the DST, and highlighted in red is the location of the outputs of the socio-economic and environmental impact assessment.

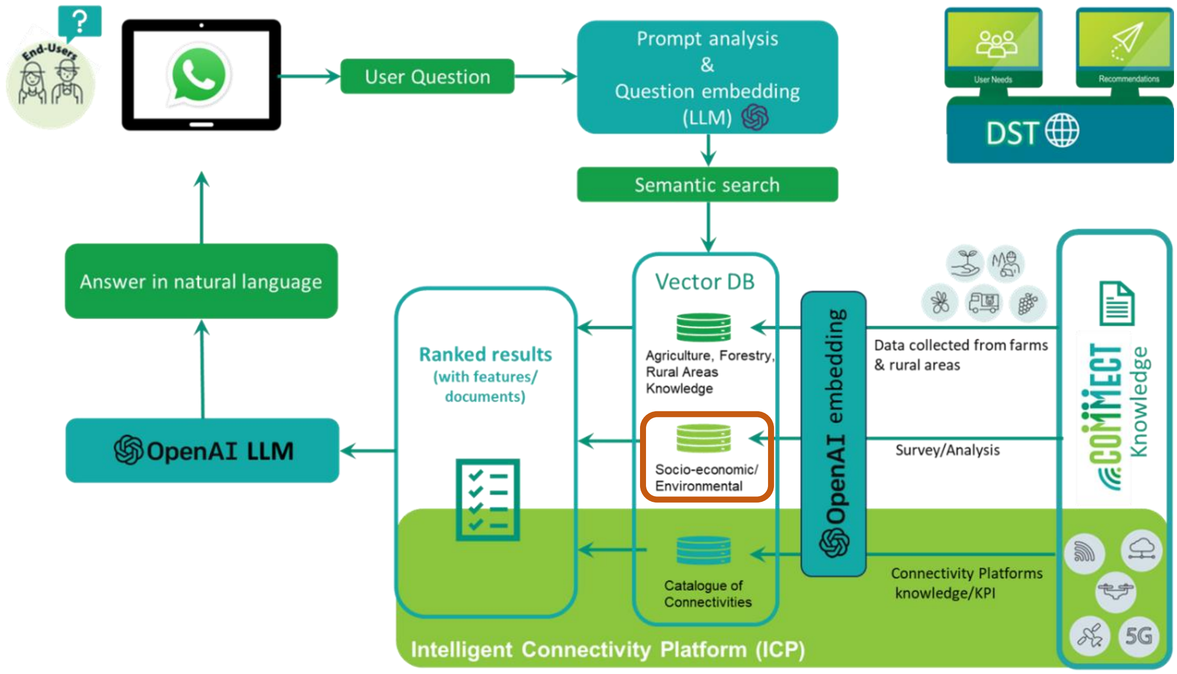


Figure 17. The logic behind the DST tool (outputs of socio-economic and environmental impact assessment will be located in highlighted area)

With the advent of generative AI and Large Language Models (LLM), the project adopted a novel approach to designing DST, i.e., leveraging the said technologies to create modern and flexible tool providing a simple, but powerful user interface and serving the needs of multiple types of stakeholders. At the same time, this approach is facilitating much easier maintenance and updating the decision logic thus ensuring continued and valid service provision.

As for the socio-economic impact, the data collected with the macro level methodology will be input for the expected socio-economic effects per country and will be displayed when the user ask prompts/questions to the DST, providing information about their location in the chat interface.

The regional level data, coming from the surveys, will give an understanding on which socio-economic impact can be expected once the technology is introduced by the collaborating organizations on a local level. The outcome of the survey analysis will be integrated in the DST and will be used as the source of information/knowledge when generating responses.

The micro level data, based on the interviews with the Living Lab leaders, will be used for two purposes. The expected socio-economic impact which will be categorized onto the indicators that have been introduced before, will show in the DST along with the macro and regional level data. All three types of data will be shown to give the user a broad impression of the expected impacts. The other purpose of the micro level data is its use in defining the business model options, which will be also used as a source of information by the DST. The DST will provide insights on potential business models through enabling users to ask questions on business model aspects (for example types of stakeholders to consider, investment structures, purpose of connectivity solution). These insights can subsequently used to describe the business model in more detail by end-users. It is currently being explored whether automated support (i.e. the DST can suggest the most 'suitable' business model) can be enabled. The business model options – worked on in Task 3.3 - will be more extensively discussed in Deliverable 3.3.

The outcomes of the proposed methodology to understand the environmental impact will be fed into the DST to display the expected effects, depending on chosen use case and location. The data will be Living Lab bound, as the measurements will take place in those specific settings. However, the outcome will be generalizable to some extent, and will be able to be enriched when additional projects will make measurements in slightly different settings, or similar use cases in a different location for example.

6. Conclusion

This deliverable addresses the methodologies proposed for evaluating the socio-economic and environmental impact of new connectivity solutions deployed in rural areas.

For the socio-economic assessment, it adopts a *combination of macro and micro perspective* of the socio-economic impact created through connectivity solutions, leveraging both geographical databases, and semi-structured interviews and surveys with stakeholders from the Living Labs.

The objective of the *micro level approach* is to assess the impact from the different use cases throughout the five LLs. In this document, preliminary results on expected social and economic impacts from exploiting the use case solutions have been reported on the Living Lab level through interviews and workshops with stakeholders.

Instead, the objective of the *macro level analysis* was to support the use case analysis results with studies of the impact of enhanced connectivity on a regional/national level. Our literature review reveals studies related to these effects in rural communities in non-developed countries, and a lack of studies in the EU countries involved in COMMECT. Our macro level analysis results have been reported in this deliverable and show a positive relationship between enhanced fixed broadband coverage and social outcomes (higher employment rates) on a regional level in some of the COMMECT countries (Norway, Denmark, and Luxembourg). However, the learnings from this macro level analysis demonstrated that it was challenging to provide data sets over a longer time-period for some of the Living Labs, especially for Turkey and Serbia. Accordingly, it was difficult to compare the macro analysis results for all the Living Lab regions/countries equally. Based on this, we have decided that the macro level analysis will not be adopted for further investigation in D5.3 and D5.6. The project will focus on the micro analysis, and collection of relevant data in the LLs.

Looking ahead for the socio-economic impact assessment, in D5.3, we will present additional findings related to socio-economic impact (based on new interactions with end-users) along with updated methodology for the socio-economic analysis. This analysis will be performed through interviews and/or online surveys and will be based on the questionnaire template presented in this deliverable. The results from the eventual trials in COMMECT by the Living Labs (using the connectivity solutions) will increase the validity of the answers from the stakeholders on the expected impact of the connectivity solutions on their business and their community/society as a whole. For some of the Living Labs the feedback will represent stakeholders from the industry on a region /national level beyond the core stakeholders in the Living Labs initially studied. The final deliverable D5.6 will include qualitative data from the interviews and survey analysis.

For the environmental assessment, first (i.e., directly related to deployment of connectivity), second (i.e., enabled through connectivity) and third-order (i.e., systemic, indirect as a result of connectivity) effects of the introduction of connectivity solutions are considered (representing data items to be collected) as part of a larger LCA assessment to provide insights into the environmental impact of new connectivity solutions. In addition, it describes how such methodologies can be considered as part of a decision-making tools for practitioners to aid and accelerate the roll-out of connectivity in practice.

Regarding the environmental assessment methodology, in this deliverable, key data to be collected and plans for modelling are presented. Actual measures, preliminary data and analyses are and will be included in later deliverables, especially in D5.6. Preliminary data and partial analyses will be included in D5.3 and complete models, analyses, findings and other results will be presented in future deliverables in WP5. The final results will include a comprehensive LCA-model about first- and second-order effects in the selected use cases. With these models, KPIs from the environmental impact assessment including climate impacts and EF-score will be formed as described in the D3.1.

The proposed methodology frameworks (socio-economic as well as environmental) in this deliverable enable us to better understand the expected socio-economic and environmental impact of the connectivity solutions in the specific settings that are created in the Living Labs (which represent rural context with limited connectivity). Such insights can be beneficial for decision makers (end-users, providers, government bodies) to support, advance or accelerate the deployment of such solutions in practice. This decision-making process (which leverages the insights generated through the socio-economic and environmental assessment framework) is supported through the COMMECT DST: therefore, the DST can provide (semi)automated support in using the frameworks for the respective Living Labs. However, as the impacts are dependent on cultural, economic, and ecological factors, the expected impacts can differ per industry domains and country. This means that the deployment of similar connectivity solutions may lead to different end results (impact) when applied in practice. Through working with the Living Labs (which will use the frameworks / DST to support the deployment of connectivity solutions) we intend to learn and explain how cultural, geographical, and societal differences influence the impact that can be generated. Throughout the COMMECT project going forward, we aim to generalize these findings as much as possible such that these can be communicated to other research and practice settings.

7. References

[1] Passani, A., Monacciani, F., Van Der Graaf, S., Spagnoli, F., Bellini, F., Debicki, M., & Dini, P. (2014). SEQUOIA: A methodology for the socio-economic impact assessment of Software-as-a-Service and Internet of Services research projects. *Research Evaluation*, *23*(2), 133–149. https://doi.org/10.1093/reseval/rvu004

[2] Vidueira, P., Díaz-Puente, J. M., & Rivera, M. (2014). Socioeconomic Impact Assessment in Ex Ante Evaluations. *Evaluation Review*, *38*(4), 309–335.

[3] Nesse, P.J, Briguglio, L. Markopoulos, I.; Hallingby, H.S. (2023a): Validation of 5G use case solutions - Simultaneous assessment of business value and social acceptance in early stages of the research and innovation projects, *Nordic and Baltic Journal of Information and Communications Technologies*, Vol, 1, pp. 37-72, (NSD Level 1) see link to article

[4] Nesse, P.J.;Nielsen, N.; Davidson, S.;Gillund, L.; Awan. M.: (2023c) *"5G in Rural Forest enables Real Time decision support and new Remote Operation Solutions",* The 3rd International Conference on Electrical, Computer, Communications and Mechatronics Engineering, ICECCME, IEEE Xplore.

[5] Cooper, R. (2017). "Idea-to-Lauch Gating Systems: Better, Faster, and More Agile," *Research-Technology Management,* vol. 60, no. 1, pp. 48-52.

[6] Ries, E. (2017). The Startup Way: How Modern Companies Use Entrepreneurial Management to Transform Culture and Drive Long-Term Growth, Currency.

[7] Larson, E., & Larson, R. (2004) "Use cases: What every project manager should know," in Larson, E. & Larson, R. (2004). Use cases: what every PMI Global Congress, Anaheim, CA, USA , 2004

[8] Nesse, P.J. and Opsahl, K.: (2023b) Activities and Output from SME and MNC collaboration on R&I projects, *Nordic and Baltic Journal of Information and Communications Technologies*, Vol. 1, 73-100.

[9] Akerman, A., Gaarder, I. and Mogstad, M., 2015. The skill complementarity of broadband internet. The Quarterly Journal of Economics, 130(4), pp.1781-1824.

[10] DeStefano, T., Kneller, R., & Timmis, J. (2018). Broadband infrastructure, ICT use and firm performance: Evidence for UK firms. *Journal of Economic Behavior & Organization*, *155*, 110-139.

[11] Hasbi, M., 2020. Impact of very high-speed broadband on company creation and entrepreneurship: Empirical Evidence. Telecommunications Policy, 44(3). Available at: https://doi.org/10.1016/j.telpol.2019.101873

[12] Canzian, G., Poy, S. and Schüller, S., 2019. Broadband upgrade and firm performance in rural areas: Quasi-experimental evidence. Regional Science and Urban Economics, 77, pp.87-103. Available at: https://doi.org/10.1016/j.regsciurbeco.2019.03.002 .

[13] Briglauer, W., Dürr, N. and Gugler, K., 2021. A retrospective study on the regional benefits and spillover effects of high-speed broadband networks: Evidence from German counties. International Journal of Industrial Organization, 74. Available at: https://doi.org/10.1016/j.ijindorg.2020.102677 .

[14] Aker, J.C., 2010. Information from markets near and far: Mobile phones and agricultural markets in Niger. American Economic Journal: Applied Economics, 2(3), pp.46-59.

[15] Jensen, R., 2007. The digital provide: Information (technology), market performance, and welfare in the South Indian fisheries sector. The quarterly journal of economics, 122(3), pp.879-924.

[16] Beuermann, D.W., McKelvey, C. and Vakis, R., 2012. Mobile phones and economic development in rural Peru. The journal of development studies, 48(11), pp.1617-1628.

[17] Flückiger, M. and Ludwig, M., 2023. Mobile phone coverage and infant mortality in sub-Saharan Africa. Journal of Economic Behavior & Organization, 211, pp.462-485.

[18] Ragin, C. C. (1999). Using qualitative comparative analysis to study causal complexity. *Health services research*, *34*(5 Pt 2), 1225.

[19] Schneider, C. Q., & Wagemann, C. (2012). *Set-theoretic methods for the social sciences: A guide to qualitative comparative analysis*. Cambridge University Press.

[20] Thomann, E., & Maggetti, M. (2020). Designing research with qualitative comparative analysis (QCA): Approaches, challenges, and tools. *Sociological Methods & Research*, *49*(2), 356-386.

[21] Ragin, C. C. (2006). Set relations in social research: Evaluating their consistency and coverage. Political Analysis, 291-310.

[22] Longest, K. C., & Vaisey, S. (2008). fuzzy: A program for performing qualitative comparative analyses (QCA) in Stata. The Stata Journal, 8(1), 79-104.

[23] Chiara Corbo, Verónica León-Bravo, Francesco Parigi, Sandra Cesari de Maria, Filippo Maria Renga/ POLIMI; Tomas Fiege Vos de Wael, Harout Jerkizian/PETE (2023). D2.1 Assessment Framework and Governance Mechanisms, Quantifarm consortium

[24] Rogers, E.M (2003). Diffusion of Innovations, 5th Edition, Free Press

[25] Soma, K.; Roebling, P.; Lopez Maciel, M.A (2023) ADOPT tool, 1st Working Meeting, October

[26] The Economist (2012): What's the greatest invention of all time? (economist.com)

[27] OECD/Eurostat. (2018). Oslo Manual 2018: Guidelines for collecting, reporting and using data on innovation, 4th Edition, The Measurement of Scientific, Technological and Innovation Activities. Paris/Eurostat, Luxemborg: OECD Publishing.

[28] Nakata, C., & Hwang, J. (2020). Design thinking for innovation: Composition, consequence, and contingency. Journal of business research, 118, 117-128. doi:10.1016/j.jbusres.2020.06.038

[29] Ragin, C. C. (2000). Fuzzy-set social science: University of Chicago Press.

[30] Ratel. (2022). An Overview of the Market of the Electronic Communications and Postal Services Markets in the Republic of Serbia in 2021.

[31] Krippendorff, K. (2018). *Content analysis: An introduction to its methodology*. Sage Publications.

[32] ISO 14040/44 (2006). Environmental Management - Life Cycle Assessment; ISO 14040: Principles and Framework; ISO 14044: Requirements and guidelines. Geneva, Switzerland, International Standardization Organization.

[33] Ruiz, D., San Miguel, G., Rojo, J., Teriús-Padrón, J.G., Gaeta, E., Arredondo, M.T., Hernández, J.F. and Pérez, J., 2022. Life cycle inventory and carbon footprint assessment of wireless ICT networks for six demographic areas. Resources, Conservation and Recycling, 176, p.105951.

[34] Rose, D.C., Sutherland, W.J., Parker, C., Lobley, M., Winter, M., Morris, C., Twining, S., Foulkes, C., Amano, T. and Dicks, L.V., 2016. Decision support tools for agriculture: Towards effective design and delivery. Agricultural systems, 149, pp.165-174.

[35] Bacenetti, J., Paleari, L., Tartarini, S., Vesely, F.M., Foi, M., Movedi, E., Ravasi, R.A., Bellopede, V., Durello, S., Ceravolo, C. and Amicizia, F., 2020. May smart technologies

reduce the environmental impact of nitrogen fertilization? A case study for paddy rice. Science of The Total Environment, 715, p.136956.

[36] Lovarelli, D., J. Bacenetti, and M. Guarino. 2020. A review on dairy cattle farming: Is precision livestock farming the compromise for an environmental, economic and social sustainable production? Journal of Cleaner Production 262: 121409.

[37] Tullo, E., A. Finzi, and M. Guarino. 2019. Review: Environmental impact of livestock farming and Precision Livestock Farming as a mitigation strategy. Science of The Total Environment 650: 2751–2760.

[38] Pardo, G., A. del Prado, J. Fernández-Álvarez, D.R. Yáñez-Ruiz, and A. Belanche. 2022. Influence of precision livestock farming on the environmental performance of intensive dairy goat farms. Journal of Cleaner Production 351: 131518.

[39] Todde, G., M. Caria, F. Gambella, and A. Pazzona. 2017. Energy and Carbon Impact of Precision Livestock Farming Technologies Implementation in the Milk Chain: From Dairy Farm to Cheese Factory. Agriculture 2017, Vol. 7, Page 79 7(10): 79.

[40] Núñez-Cárdenas, P., B. Diezma, G.S. Miguel, C. Valero, and E.C. Correa. 2022. Environmental LCA of Precision Agriculture for Stone Fruit Production. Agronomy 2022, Vol. 12, Page 1545 12(7): 1545.

[41] Pradel, M., M. de Fays, and C. Seguineau. 2022. Comparative Life Cycle Assessment of intra-row and inter-row weeding practices using autonomous robot systems in French vineyards. Science of The Total Environment 838: 156441.

[42] Sanches, G.M., R. de O. Bordonal, P.S.G. Magalhães, R. Otto, M.F. Chagas, T. de F. Cardoso, and A.C. dos S. Luciano. 2023. Towards greater sustainability of sugarcane production by precision agriculture to meet ethanol demands in south-central Brazil based on a life cycle assessment. Biosystems Engineering 229: 57–68.

[43] Medel-Jiménez, F., G. Piringer, A. Gronauer, N. Barta, R.W. Neugschwandtner, T. Krexner, and I. Kral. 2022. Modelling soil emissions and precision agriculture in fertilization life cycle assessment - A case study of wheat production in Austria. Journal of Cleaner Production 380: 134841.

[44] Fazio, S., Zampori, L., De Schryver, A., Kusche, O., & Diaconu, E. (2020). Guide for EF compliant data sets. *Luxembourg: Publications Office of the European Union*.

[45] Sala S., Cerutti A.K., Pant R., Development of a weighting approach for the Environmental Footprint, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-68042-7, EUR 28562, doi 10.2760/945290.

[46] European Telecommunications Standards Institute (2015). ETSI ES 203 199. V1.3.1 (2015-02). Environmental Engineering (EE); Methodology for environmental Life Cycle Assessment (LCA) of Information and Communication Technology (ICT) goods, networks and services.

[47] International Telecommunication Union (2014). ITU.T L.1410. Methodology for environmental life cycle assessments of information and communication technology goods, networks and services

[48] Alliance for IoT and Edge Computing Innovation (2022). IoT and Edge Computing Carbon Footprint Measurement Methodology. Release 1.1. AIOTI WG Digital for Green.

[49] Horner, N.C., Shehabi, A. and Azevedo, I.L., 2016. Known unknowns: indirect energy effects of information and communication technology. Environmental Research Letters, 11(10), p.103001.

[50] Russell, S. 2019. Estimating and reporting the comparative emissions impacts of products. Working paper, World Resources Institute.

[51] The Carbon Trust (2017). ICT Sector Guidance built on the GHG Protocol Product Life Cycle Accounting and Reporting Standard.

[52] Hilty, L.M. and Aebischer, B., 2015. ICT for sustainability: An emerging research field. ICT innovations for Sustainability, pp.3-36.

[53] Ekvall, T., Azapagic, A., Finnveden, G., Rydberg, T., Weidema, B.P. and Zamagni, A., 2016. Attributional and consequential LCA in the ILCD handbook. The International Journal of Life Cycle Assessment, 21, pp.293-296.

[54] Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., and Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, [online] 21(9), pp.1218–1230. Available at: <http://link.springer.com/10.1007/s11367-016-1087-8> [Accessed 15 March 2023].

[55] Ferrara, C. and De Feo, G., 2018. Life cycle assessment application to the wine sector: a critical review. Sustainability, 10(2), p.395.

[56] Christ, K.L. and Burritt, R.L., 2013. Critical environmental concerns in wine production: an integrative review. Journal of Cleaner Production, 53, pp.232-242.

[57] Hannah, L., Roehrdanz, P.R., Ikegami, M., Shepard, A.V., Shaw, M.R., Tabor, G., Zhi, L., Marquet, P.A. and Hijmans, R.J., 2013. Climate change, wine, and conservation. Proceedings of the National Academy of Sciences, 110(17), pp.6907-6912.

[58] Casolani, N., D'Eusanio, M., Liberatore, L., Raggi, A. and Petti, L., 2022. Life Cycle Assessment in the wine sector: A review on inventory phase. Journal of Cleaner Production, p.134404.

[59] Vázquez-Rowe, I., Rugani, B. and Benetto, E., 2013. Tapping carbon footprint variations in the European wine sector. Journal of Cleaner Production, 43, pp.146-155.

[60] EC, 2018. A sustainable bioeconomy for Europe: strengthening the connection between economy, society and the environment. Available at. https://ec.europa.eu/research/bioeconomy/pdf/ec_bioeconomy_strategy_2018.pdf#view=fit&pagemode=none.

[61] González-García, S., Krowas, I., Becker, G., Feijoo, G. and Moreira, M.T., 2013. Cradle-to-gate life cycle inventory and environmental performance of Douglas-fir roundwood production in Germany. Journal of Cleaner Production, 54, pp.244-252.

[62] Michelsen, O., 2008. Assessment of land use impact on biodiversity: proposal of a new methodology exemplified with forestry operations in Norway. The International Journal of Life Cycle Assessment, 13, pp.22-31.

[63] D'amato, D., Gaio, M. and Semenzin, E., 2020. A review of LCA assessments of forest-based bioeconomy products and processes under an ecosystem services perspective. Science of the Total Environment, 706, p.135859.

[64] González-García, S., Moreira, M.T., Dias, A.C. and Mola-Yudego, B., 2014. Cradle-to-gate Life Cycle Assessment of forest operations in Europe: Environmental and energy profiles. Journal of cleaner production, 66, pp.188-198.

[65] Perdomo E, E.A., Schwarzbauer, P., Fürtner, D. and Hesser, F., 2021. Life Cycle Assessment of Agricultural Wood Production—Methodological Options: a Literature Review. BioEnergy Research, 14, pp.492-509.

[66] Lesschen J.P., van den Berg M., Westhoek H.J., Witzke H.P., Oenema O. (2011). Greenhouse gas emission profiles of European livestock sectors. Animal Feed Science and Technology 166–167, 16-28

[67] Scherrer, L., B. Tomasik, O. Rueda, and S. Pfister. 2018. Framework for integrating animal welfare into life cycle sustainability assessment. International Journal of Life Cycle Assessment 23(7): 1476–1490.

[68] Cappelletti, G.M., Grilli, L., Nicoletti, G.M. and Russo, C., 2017. Innovations in the olive oil sector: A fuzzy multicriteria approach. Journal of Cleaner Production, 159, pp.95-105.

[69] Van Evert, F.K., Gaitán-Cremaschi, D., Fountas, S. and Kempenaar, C., 2017. Can precision agriculture increase the profitability and sustainability of the production of potatoes and olives?. Sustainability, 9(10), p.1863.

[70] De Luca, A.I., Falcone, G., Stillitano, T., Iofrida, N., Strano, A. and Gulisano, G., 2018. Evaluation of sustainable innovations in olive growing systems: A Life Cycle Sustainability Assessment case study in southern Italy. Journal of Cleaner Production, 171, pp.1187-1202.

[71] Banias, G., Achillas, C., Vlachokostas, C., Moussiopoulos, N. and Stefanou, M., 2017. Environmental impacts in the life cycle of olive oil: A literature review. Journal of the Science of Food and Agriculture, 97(6), pp.1686-1697.

[72] Beaufoy, G., Pienkowski, M., 2002. The Environmental Impact of Olive Oil Production in European Union: Practical Options for Improving the Environmental Impact. European Environment Agency.

[73] Mohamad, R.S., Verrastro, V., Cardone, G., Bteich, M.R., Favia, M., Moretti, M. and Roma, R., 2014. Optimization of organic and conventional olive agricultural practices from a Life Cycle Assessment and Life Cycle Costing perspectives. Journal of Cleaner Production, 70, pp.78-89.

[74] Loiseau, E., L. Aissani, S. Le Féon, F. Laurent, J. Cerceau, S. Sala, and P. Roux. 2018. Territorial Life Cycle Assessment (LCA): What exactly is it about? A proposal towards using a common terminology and a research agenda. Journal of Cleaner Production 176: 474–485.

[75] Larrey-Lassalle, P, Armand Decker, S, Perfido, D, Naneci, S & Rugani, B 2022, 'Life Cycle Assessment Applied to Nature-Based Solutions: Learnings, Methodological Challenges, and Perspectives from a Critical Analysis of the Literature', Land, vol. 11, no. 5, p. 649.

[76] Babí Almenar, J., C. Petucco, G. Sonnemann, D. Geneletti, T. Elliot, and B. Rugani. 2023. Modelling the net environmental and economic impacts of urban nature-based solutions by combining ecosystem services, system dynamics and life cycle thinking: An application to urban forests. Ecosystem Services 60: 101506.

[77] Sherazi, H.H.R., L.A. Grieco, M.A. Imran, and G. Boggia. 2021. Energy-Efficient LoRaWAN for Industry 4.0 Applications. IEEE Transactions on Industrial Informatics 17(2): 891–902.

[78] Gawron, J.H., G.A. Keoleian, R.D. De Kleine, T.J. Wallington, and H.C. Kim. 2018. Life Cycle Assessment of Connected and Automated Vehicles: Sensing and Computing Subsystem and Vehicle Level Effects. Environmental Science and Technology 52(5): 3249–3256. https://pubs-acs-org.proxy.bnl.lu/doi/full/10.1021/acs.est.7b04576. Accessed June 21, 2023.

[79] Sacco, P., E.R. Gargano, A. Cornella, D. Don, and F. Mazzetto. 2021. Digital sustainability in smart agriculture. *2021 IEEE International Workshop on Metrology for Agriculture and Forestry, MetroAgriFor 2021 - Proceedings*: 471–475.

[80] Pradel, M. 2023. Life cycle inventory data of agricultural tractors. *Data in Brief* 48: 109174.

[81] Hillerström, H. and U. Troborg. 2010. Customized LCA for Network Cameras. KTH Sweden. https://www.diva-portal.org/smash/get/diva2:444443/FULLTEXT01.pdf. Accessed November 6, 2023.

[82] Campbell Scientific. 2020. LWS: Leaf-wetness sensor. Logan, UT. https://s.campbellsci.com/documents/us/product-brochures/b_lws.pdf.

[83] Stolaroff, J.K., C. Samaras, E.R. O'Neill, A. Lubers, A.S. Mitchell, and D. Ceperley. 2018. Energy use and life cycle greenhouse gas emissions of drones for commercial package delivery. Nature Communications 2018 9:1 9(1): 1–13. https://www-nature-com.proxy.bnl.lu/articles/s41467-017-02411-5. Accessed September 5, 2023.

[84] Koiwanit, J. 2018. Analysis of environmental impacts of drone delivery on an online shopping system. Advances in Climate Change Research 9(3): 201–207.

[85] Western Digital. 2021. Life Cycle Assessment: Western Digital WD Green(tm) SATA Solid State Drive (SSD). https://documents.westerndigital.com/content/dam/doc-library/en_us/assets/public/western-digital/collateral/analyst-report/life-cycle-assesment-wd-green-sata-ssd-western-digital.pdf.

[86] Ding, Y., H. Duan, M. Xie, R. Mao, J.J. Wang, and W. Zhang. 2022. Carbon emissions and mitigation potentials of 5G base station in China. Resources, Conservation and Recycling 182: 106339.

[87] Chiew, Y.L. and B. Brunklaus. 2021. *Life cycle assessment of Internet of Things(IoT) solution in Södertälje municipality-A smart waste collection system*. Mölndal. https://www.sodertalje.se/contentassets/74ac81d93571497fb3aff3b21210e6a1/s_iot_lca-report-20211005_final.pdf

[88] Bieser, J.C.T., B. Salieri, R. Hischier, and L. Hilty. 2020. *Next generation mobile networks: Problem or opportunity for climate protection?* Zurich, Switzerland. https://plus.empa.ch/images/5G climate protection_University of Zurich_Empa.pdf. Accessed August 7, 2023.

[89] Guerid, J., J.B. Dore, J. Reverdy, B. Reig, A. Clemente, and L. Di Cioccio. 2022. Toward Eco-Design of a 5G mmWave Transmitarray Antenna Based on Life Cycle Assessment. 2022 Joint European Conference on Networks and Communications and 6G Summit, EuCNC/6G Summit 2022: 440–445.

[90] Williams, L., B.K. Sovacool, and T.J. Foxon. 2022. The energy use implications of 5G: Reviewing whole network operational energy, embodied energy, and indirect effects. Renewable and Sustainable Energy Reviews 157: 112033.

[91] Pihkola, H., M. Hongisto, O. Apilo, and M. Lasanen. 2018. Evaluating the Energy Consumption of Mobile Data Transfer—From Technology Development to Consumer Behaviour and Life Cycle Thinking. Sustainability 2018, Vol. 10, Page 2494 10(7): 2494. https://www.mdpi.com/2071-1050/10/7/2494/htm. Accessed August 22, 2023.

[92] Andrae, A.S.G. and T. Edler. 2015. On Global Electricity Usage of Communication Technology: Trends to 2030. *Challenges 2015, Vol. 6, Pages 117-157* 6(1): 117–157. https://www.mdpi.com/2078-1547/6/1/117/htm. Accessed September 12, 2023.

Appendix

Appendix 1: Survey questionnaire

COMMECT – SURVEY

Acquiring information about companies, departments, individuals (self-employed) that are involved in implementation of new connectivity (5G)/ICT-solutions.

SECTION 1

Here, we would like to know more about the company/organizations and your use of connectivity/ICT based solutions - general info about you and your company's age, size, management, and employees. When we say "company", we also mean "self-employed".

We would like the manager to answer the questionnaire (alternatively head of innovation/R&D or societal/environmental development etc. - or a project manager).

Respondent-ID code: ____

Q1. The company year of foundation: ____

Q2. The postal code for your main operations/responsibility area: ____________________

Q3. Describe the main activities carried out/offered by your company: (Norway: Do you represent a machine contractor company or are you a forestry manager? (Tick one)

Q4. What is your position in the company/organisation:____________________________

Q5. About how many employees did the company/organisation have in 2023: (tick one only).

a) 1 .... ☐
b) 2 – 5 .... ☐
c) 6 - 10 .... ☐
d) 11 – 50 .... ☐
e) 51 - 250 .... ☐
f) more than 250 .... ☐

g) number if you know: ______________________

Q6. Please estimate the share of female employees that your company/organisation had in 2023:

a) 0 - 10 % .... ☐
b) 11 - 20 % .... ☐
c) 21 – 40 % .... ☐
d) More than 40 % .... ☐
e) Don't know .... ☐
f) Not relevant .... ☐

Q7a. What is your level / degree of education? (tick one)

Primary/secondary school ☐
High school ☐
Bachelor's degree ☐
Master's degree or higher ☐

Q7b. Where are you from (your origin)? (tick one)

From the county ☐
From the country, but outside the county ☐
From another country ☐

Q8. Approximately how many (%) employees in your company/organisation in 2023 have completed a high level degree of education (Master or higher)

	Tick only one
0%	☐
1% to less than 5%	☐
5% to less than 10%	☐
10% to less than 25%	☐
25% to less than 50%	☐
50% to less than 75%	☐
75% or more	☐
Not relevant/don't know	☐

Q9. From where has your company recruited employees in the last 5 years? (tick all that apply)

From the region	☐
From the country, but outside the region	☐
From outside the country	☐
From the same sector as the company	☐
From related sectors	☐
From completely different sectors	☐
Not relevant/don't know	☐

SECTION 2. ABOUT YOUR COMPANY'S/ORGANISATIONS INNOVATION ACTIVITY AND COLLABORATION WITH EXTERNAL PARTNERS

Q10. During the three years 2020 to 2022, did you and or your company introduce any:

*This question concerns product innovation, which is a new or improved good or service that differs significantly from the company's previous goods or services and which has been implemented on the market. Include: significant changes to the design of a good, digital goods or services.	Yes	No	Not relevant
a) New or improved goods*	☐	☐	☐
b) New or improved services*	☐	☐	☐

Q11. During 2020 to 2022, did your enterprise introduce any of the following types of new or improved processes that differ significantly from your previous processes?

*This question concerns business process innovation, which is a new or improved business process for one or more business functions that differ significantly from previous business processes, and which has been implemented within the company.	**Yes**	**No**	**Not relevant**
a) Methods for producing or developing goods or providing services*	☐	☐	☐
b) Logistics, delivery or distribution methods*	☐	☐	☐
c) Methods for information processing or communication*	☐	☐	☐
d) Methods for accounting or other administrative operations*	☐	☐	☐
e) Business practices for organising procedures or external relations*	☐	☐	☐

f) Methods of organising work responsibility, decision making or human resource management*	☐	☐	☐
g) Marketing methods for promotion, packaging, pricing, product placement or after sales services*	☐	☐	☐

Q12. Please indicate the type of innovation co-operation partner by location (for the period 2020-2022): (tick all that apply)

Type of co-operation partner	**Locally/ Regional/ county**	**Your country**	**Other countries**	**Not Relevant**
a) Private business enterprises outside your enterprise group	☐	☐	☐	☐
b) Consultants, commercial labs, or private research institutes	☐	☐	☐	☐
c) Suppliers of equipment, materials, components or software	☐	☐	☐	☐
d) Enterprises that are your clients or customers	☐	☐	☐	☐
e) Enterprises that are your competitors	☐	☐	☐	☐
f) Other enterprises	☐	☐	☐	☐
g) Enterprises within your enterprise group	☐	☐	☐	☐
h) Universities or other higher education institutions	☐	☐	☐	☐
i) Government or public research institutes	☐	☐	☐	☐
j) Clients or customers from the public sector	☐	☐	☐	☐
k) Non-profit organisations	☐	☐	☐	☐

SECTION 3. ADDITIONAL KEY INFORMATION ABOUT THE SURVEYED COMPANY (EXPORT, R&D EXPENDITURE, DEGREE OF TRUST) (Only for company-respondents)

Q13. Give an estimate on the company's turnover in 2023: ________

Don't know___________

Q14. Approximately, what was the percentage of turnover in 2020 from:

a) Customers located in your county ______________ %
b) Customers located in your country (outside the county) ______________ %
c) Customers located in other countries ______________ %

Q15. Estimate the % of your company's/organisation's profit that were spend on innovation and research and development (R&D) in 2022?

Estimate (%)____

Don't know_____________

Q16. Did your company patent inventions in the 2020-2022 period?

Yes ☐ No ☐ Don't know ☐

Q17. Please indicate your opinion and viewpoints on the following questions:

1=very low,2=low,3=neutral,4=high, 5=very high	**1**	**2**	**3**	**4**	**5**	**Not relevant**	**Don't know**
a) To what degree do you have a positive attitude/opinion towards the adoption of new technologies in your work or sector?	☐	☐	☐	☐	☐	☐	☐
b) How would you characterize the degree of trust you have towards the other regional companies in your sector?	☐	☐	☐	☐	☐	☐	☐
c) How would you characterize the degree of trust you have towards other companies in your sector, but outside your region?	☐	☐	☐	☐	☐	☐	☐

SECTION 4. APPROACH TO DEVELOPMENT OF PRODUCT/SERVICE SOLUTIONS

In this section, we are interested in hearing more about how you work with development and significant improvements of products and services.

Q18. Will you assess that you work in the following ways: (Tick all that apply per row)

1=strongly disagree, 2= disagree, 3 =neither disagree /nor agree, 4 agree and 5 strongly agree	**1**	**2**	**3**	**4**	**5**	**Not rele-vant**	**Don't know**
a) We assess the needs and problems of customers and other stakeholders through analysis of data on the experience of users	☐	☐	☐	☐	☐	☐	☐
b) We assess the needs and problems of customers and other stakeholders through interviews, focus group interviews, and brainstorming/idea-generation workshops with users and stakeholders	☐	☐	☐	☐	☐	☐	☐
c) We develop early versions of a prototype/proof of concept of a solution intended to solve the needs and problems of the customers and stakeholders	☐	☐	☐	☐	☐	☐	☐
d) We validate the prototype/proof of concept against technological requirements in tests and experiments	☐	☐	☐	☐	☐	☐	☐
e) We validate the prototype against usability requirements in tests and experiments	☐	☐	☐	☐	☐	☐	☐
f) We validate the prototype against business requirements in tests and experiments	☐	☐	☐	☐	☐	☐	☐
g) We validate the prototype against socio-economic requirements in tests and experiments	☐	☐	☐	☐	☐	☐	☐
h) We validate the prototype against environmental requirements in tests and experiments	☐	☐	☐	☐	☐	☐	☐
i) Based on the results from the commercial and technological validations we intend to repeat the test/experiments with a revised prototype	☐	☐	☐	☐	☐	☐	☐
j) All in all, we follow an agile (repetitive tests) development process when developing new or improved product and service solutions within our industry	☐	☐	☐	☐	☐	☐	☐

SECTION 5. SOCIO-ECONOMIC IMPACT FROM IMPLEMENTATION OF NEW CONNECTIVITY/ICT SOLUTIONS

There are several areas of use for smart communication solutions in the forestry industry. With the next generation mobile network (5G/IoT), the connectivity/network becomes faster, and several devices can be connected to the network at the same time. This can, for example, help realize the following use cases [**Living Lab specific use case descriptions, Norway example below**]:

• Digital support for operators in forest machines using VR and drones. Here, operators of forest machines can receive assistance from experts, regardless of where the person concerned is geographically located, in addition to information from various drones and sensors to make the best possible choices in felling, thinning and maintenance work. At the same time, this ensures that rare species and biotopes remain untouched, and helps to maintain environmental certification and fewer fines from the authorities.

• Real-time situation and decision support for emergency services. Here, fire, police etc. and other agencies to have identical information sent to their terminals from drones with heat-seeking cameras etc. for the coordination of joint efforts in forest fires and other emergency situations. The drones can also simplify requirements for a fire watch after work at extreme temperatures."

Q19. Have you implemented any new ICT solutions/connectivity enhancement (that are based on broadband /4G/5G/IoT) in the last three years **[Living Lab specific]?**

Yes	No	Not relevant/don't know
☐	☐	☐

Q20. If yes, please describe the most important ICT solution/connectivity enhancement **[Living Lab specific]?**:

____

Q21. Have you experienced any improvements and benefits from the implementation of this most important ICT solution/connectivity enhancement **[Living Lab specific]?:**

Yes	No	Not yet, but we expect to	Not relevant/don't know
☐	☐	☐	☐

Q22. If you have reported “yes” or “not yet, but we expect to” in Q21, we would like you to report the characteristics and level of the improvements or benefits that you either have experienced or expect from introducing the new most important ICT solution/connectivity enhancement **[Living Lab specific].**

	Level of benefit/improvement						
1=very low, 2=low, 3=neutral, 4=high, 5=very high	**1**	**2**	**3**	**4**	**5**	**Not rele-vant**	**Don't know**
Financial							
a) Increased revenue from new products & services?	☐	☐	☐	☐	☐	☐	☐
b) Reduced cost and time of value chain activities?	☐	☐	☐	☐	☐	☐	☐
c) Increased profit (net revenues vs. costs)?	☐	☐	☐	☐	☐	☐	☐
Social							
d) Increased goodwill from the community?	☐	☐	☐	☐	☐	☐	☐
e) Increased law/regulation alignment (incl. certification)?	☐	☐	☐	☐	☐	☐	☐
f) Increased efficiency of digitalization and automation?	☐	☐	☐	☐	☐	☐	☐
g) Increased degree of new goods and services (products)?	☐	☐	☐	☐	☐	☐	☐
h) Increased user experience for the operation of value chain activities?	☐	☐	☐	☐	☐	☐	☐
i) Improved health and safety regarding the operation of value-chain activities?	☐	☐	☐	☐	☐	☐	☐
j) Improved privacy for employees and operators?	☐	☐	☐	☐	☐	☐	☐
k) Increased digital inclusion/accessibility for citizens and other community/ municipality actors?	☐	☐	☐	☐	☐	☐	☐
l) Improved quality of life/well-being for citizens/ community?	☐	☐	☐	☐	☐	☐	☐
m) Improved trust among stakeholders in the value chain/ ecosystem?	☐	☐	☐	☐	☐	☐	☐
n) Improved management of crises and emergencies for the municipality?	☐	☐	☐	☐	☐	☐	☐
Environmental							
o) Reduced CO2 emissions?	☐	☐	☐	☐	☐	☐	☐
p) Reduced energy consumption?	☐	☐	☐	☐	☐	☐	☐
q) Reduced waste and materials consumption ?	☐	☐	☐	☐	☐	☐	☐

r) Reduced pesticide usage?	☐	☐	☐	☐	☐	☐	☐
s) Saving water?	☐	☐	☐	☐	☐	☐	☐
t) Saving species diversity, and cultural heritage?	☐	☐	☐	☐	☐	☐	☐

Q23. If you scored 4 or 5 (high or very high benefit from new connectivity/ICT solutions on financial, social or environmental aspects - could you estimate approximately how much (%) the size of improvement will be?

a) Increased revenues from new connectivity/ICT solutions	Tick only one
1% to 5%	☐
5% to 10%	☐
10% to 25%	☐
25% to 50%	☐
50% or more	☐
not relevant/don't know	☐

b) Reduced costs from new connectivity/ICT solutions	Tick only one
1% to 5%	☐
5% to 10%	☐
10% to 25%	☐
25% to 50%	☐
50% or more	☐
not relevant/don't know	☐

c) Increased profit from new connectivity/ICT solutions	Tick only one
1% to 5%	☐
5% to 10%	☐
10% to 25%	☐
25% to 50%	☐
50% or more	☐
not relevant/don't know	☐

d) Improvement of social effects (e.g. for individuals and local community) from new connectivity/ICT solutions	Tick only one
1% to 5%	☐
5% to 10%	☐

10% to 25%	☐
25% to 50%	☐
50% or more	☐
not relevant/don't know	☐

e) Improvement of environmental effects (e.g. air, water, soil, energy efficiency) from new connectivity/ICT solutions	Tick only one
1% to 5%	☐
5% to 10%	☐
10% to 25%	☐
25% to 50%	☐
50% or more	☐
not relevant/don't know	☐

Q24. Do you have any additional comments:

Thank you for filling in our survey form.

From TNO and TNOR

Virag Szijjarto (TNO) and Per J. Nesse (TNOR)

Appendix 2: Consent form

This form applies for respondents filling in survey questionnaire in paper. Text will be adapted to online survey version.

Survey Participation Consent Form

Survey: Impact of Connectivity/ICT solutions in the COMMECT Living Labs **Administering organization**: TNO, Netherlands **Researchers**: Virag Szijjarto (TNO) and Per J. Nesse (TNOR)

The purpose of this survey study is to investigate the expected improvements or benefits from introducing new connectivity technologies and ICT solutions in companies' processes/tasks that will be trailed in the living lab pilots. Moreover, we are interested in additional information about innovation, collaboration and working activities in your company/organization.

Your participation in this study is entirely voluntary and you may withdraw at any time. An anonymous case number will be obtained in connection with this study to allow appropriate identification and monitoring of study participants. Any information that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. You will not be identified individually in any of the information we get from this study or in any of the research reports/publications.

I/We hereby give consent to be included in the COMMECT – survey "Impact from Connectivity/ICT solutions in the COMMECT Living Labs". I/We understand that the information will be used solely to improve the current understanding of the highlighted research area. I/We understand that my/our personal details will not be used for any other purpose than case identification and will not be included in study outcomes.

Name of Person (please print):……………………………………………………………….. Signature of Person:……………………………………………………………………………. Date:…………………………………………………………………………………………… *Person signing must be 18 years of age or over*

Appendix 3: Example of Calculating Avoided Carbon Emissions in industrial sectors, when ICT is applied

An example for the calculation of avoided carbon emissions in industrial sectors, when ICT is applied, is presented in (Alliance for IoT and Edge Computing Innovation 2023) and is introduced below. In particular, as described in (Alliance for IoT and Edge Computing Innovation 2023) this is a quantitative method, where the avoided emissions in vertical/industrial sectors, when applying ICT, can be calculated for all LCA phases, excluding the LCA re-use and recycling phases. This equation includes as well factors, as type of service and the load that the ICT infrastructure needs to support over a period of time. In particular, for the calculation of the ICT infrastructure emissions in the operation/use LCA phase, the quantitative method specified in ITU-T L.1333 is proposed.

The proposed Total Avoided Carbon Emissions equation is provided below and is visualized in Figure 18. Note that Equation 5, updates Equation 3 that was specified in (Alliance for IoT and Edge Computing Innovation 2022).

Eq. 5: $\mathbf{TAE_{(l)(ts)} = (T\_EBs\_nict_{(l)(ts)} + T\_EictBs_{(l)(ts)}) - (T\_EGr\_nict_{(l)(ts)} + T\_EictGr_{(l)(ts)})}$,

Where:

- $\mathbf{TAE_{(l)(ts)}}$ Total Avoided Carbon Emission Scenario for: (1) the complete LCA, excluding the Reuse and Recycle phases, (2) for a certain Load and (3) for a type of service, e.g. follow the classification specified by ITU-T for 5G type of services;
- $\boldsymbol{T\_EBs\_nict}_{(l)(ts)}$ Total Carbon Emission Scenario, for Baseline scenario (*Bs*), but excluding the carbon emission of the applied ICT infrastructure, i.e., carbon emissions of *ictBs*, for: (1) the complete LC phases, excluding the Reuse and Recycle phases, (2) for a certain Load and (3) for a type of service, e.g. follow the classification specified by ITU-T for 5G type of services;
    - *Where:* $\boldsymbol{T\_EBs\_nict}_{(l)(ts)} = \boldsymbol{T\_EBs\_nict^{M}_{(l)(ts)}} + \boldsymbol{T\_EBs\_nict^{P}_{(l)(ts)}} + \boldsymbol{T\_EBs\_nict^{O}_{(l)(ts)}} + \boldsymbol{T\_EBs\_nict^{D}_{(l)(ts)}}$
- $\boldsymbol{T\_EictBs}_{(l)(ts)}$ Total ICT Carbon Emission for Baseline Scenario, i.e., *ictBs,* for: (1) the complete LCA, excluding the Reuse and Recycle phases, (2) for a certain Load and (3) for a type of service, e.g. follow the classification specified by ITU-T for 5G type of services;
    - *Where:* $\boldsymbol{T\_EictBs}_{(l)(ts)} = \boldsymbol{T\_EictBs^{M}_{(l)(ts)}} + \boldsymbol{T\_EictBs^{P}_{(l)(ts)}} + \boldsymbol{T\_EictBs^{O}_{(l)(ts)}} + \boldsymbol{T\_EictBs^{D}_{(l)(ts)}}$
    - An example of calculating $T\_EictBs_{(l)(ts)}$ in the LC use/operation phase can be realized by using the approach defined in ITU T L.1333, "L.1333 : Carbon data intensity for network energy performance monitoring.
- $\boldsymbol{T\_EGr\_nict}_{(l)(ts)}$ Total ICT Carbon Emission Scenario, for Green enabled scenario, but excluding the carbon emission of the applied ICT infrastructure, i.e., carbon emissions of *ictGr*, for: (1) the complete LCA, excluding the Reuse and Recycle phases, (2) for a certain Load and (3) for a type of service, e.g. follow the classification specified by ITU-T for 5G type of services;
    - *Where:* $\boldsymbol{T\_EGr\_nict}_{(l)(ts)} = \boldsymbol{T\_EGr\_nict^{M}_{(l)(ts)}} + \boldsymbol{T\_EGr\_nict^{P}_{(l)(ts)}} + \boldsymbol{T\_EGr\_nict^{O}_{(l)(ts)}} + \boldsymbol{T\_EGr\_nict^{D}_{(l)(ts)}}$
- $\boldsymbol{T\_EictGr}_{(l)(ts)}$ Total ICT Carbon Emission for Green enabled Scenario, i.e., *ictGr*, for: (1) the complete LCA, excluding the Reuse and Recycle phases, (2) for a certain Load and (3) for a type of service, e.g. follow the classification specified by ITU-T for 5G type of services;

- Where: $\boldsymbol{T\_EictGr}_{(l)(ts)} = \boldsymbol{T\_EictGr}^{\boldsymbol{M}}_{(l)(ts)} + \boldsymbol{T\_EictGr}^{\boldsymbol{P}}_{(l)(ts)} + \boldsymbol{T\_EictGr}^{\boldsymbol{O}}_{(l)(ts)} + \boldsymbol{T\_EictGr}^{\boldsymbol{D}}_{(l)(ts)}$
- An example of calculating $T\_EictGr_{(l)(ts)}$ in the LC use/operation phase can be realized by using the approach defined in ITU T L.1333, "L.1333 : Carbon data intensity for network energy performance monitoring.

- Note that the superscripts **M**, **P**, **O**, **D**, shown in the equation terms introduced above and in Figure 18, denote that the carbon emissions calculations are related to the LC phases: Material, Product, Operation, Discard, respectively.

It can be derived that:

Eq. 6 $\boldsymbol{T\_EBs\_nict}^{\boldsymbol{M}}_{(l)(ts)} = \sum_{\boldsymbol{m=1}}^{\boldsymbol{LBs\_nict}} \boldsymbol{EBs\_nict}^{\boldsymbol{M}}_{(\boldsymbol{m})(\boldsymbol{l})(\boldsymbol{ts})}$

Eq. 7 $\boldsymbol{T\_EBs\_nict}^{\boldsymbol{P}}_{(l)(ts)} = \sum_{\boldsymbol{m=1}}^{\boldsymbol{LBs\_nict}} \boldsymbol{EBs\_nict}^{\boldsymbol{P}}_{(\boldsymbol{m})(\boldsymbol{l})(\boldsymbol{ts})}$

Eq. 8 $\boldsymbol{T\_EBs\_nict}^{\boldsymbol{O}}_{(l)(ts)} = \sum_{\boldsymbol{m=1}}^{\boldsymbol{LBs\_nict}} \boldsymbol{EBs\_nict}^{\boldsymbol{O}}_{(\boldsymbol{m})(\boldsymbol{l})(\boldsymbol{ts})}$

Eq. 9 $\boldsymbol{T\_EBs\_nict}^{\boldsymbol{D}}_{(l)(ts)} = \sum_{\boldsymbol{m=1}}^{\boldsymbol{LBs\_nict}} \boldsymbol{EBs\_nict}^{\boldsymbol{D}}_{(\boldsymbol{m})(\boldsymbol{l})(\boldsymbol{ts})}$

Where:

- $\boldsymbol{EBs_{nict}}^{\boldsymbol{M}}_{(\boldsymbol{m})(\boldsymbol{l})(\boldsymbol{ts}}$*: represents carbon emission of each product/components (m) used in in the Baseline scenario, excluding the ICT infrastructure, obtained in the LC Material phase; Note that in this case the subscripts (l) and (ts) can be discarded, since they are not relevant;*
- $\boldsymbol{EBs_{nict}}^{\boldsymbol{P}}_{(\boldsymbol{m})(\boldsymbol{l})(\boldsymbol{ts}}$*: represents carbon emission of each product/components (m) used in in the Baseline scenario, excluding the ICT infrastructure, obtained in the LC Production phase. Note that in this case the subscripts (l) and (ts) can be discarded, since they are not relevant;*
- $\boldsymbol{EBs_{nict}}^{\boldsymbol{O}}_{(\boldsymbol{m})(\boldsymbol{l})(\boldsymbol{ts}}$*: represents carbon emission of each product/components (m) used in in the Baseline scenario, excluding the ICT infrastructure, obtained in the LC Operation phase;*
- $\boldsymbol{EBs_{nict}}^{\boldsymbol{D}}_{(\boldsymbol{m})(\boldsymbol{l})(\boldsymbol{ts}}$*: represents carbon emission of each product/components (m) used in in the Baseline scenario, excluding the ICT infrastructure, obtained in the LC Disposal phase. Note that in this case the subscripts (l) and (ts) can be discarded, since they are not relevant;*
- ***LBs_nict****: total number of product/components (m) used in the Baseline scenario, excluding the ICT infrastructure*
- **M**: denotes the LC Material phase

Note that the same type of equations can be derived for: $\mathbf{T\_EGr\_nict}_{(l)(ts)}$; $\mathbf{T\_EictBs}_{(l)(ts)}$; $\mathbf{T\_EictGr}_{(l)(ts)}$;

Equation for Total ICT Avoided Carbon Emissions:

Eq. 10: $\boldsymbol{TAE\_ICT_{(l)(ts)} = T\_\ EictBs_{(l)(ts)} - T\_\ EictGr_{(l)(ts)}}$,

Where:

- $TAE\_ICT_{(l)(ts)}$: Total ICT Avoided Carbon Emission is a metric to measure the ICT carbon emission benefits, when replacing the ICT infrastructure used in the Baseline scenario, i.e., *ictBs*, with the ICT solution used in a Green enablement scenario, i.e., *ictGr.*

- Note that in certain situations, e.g., including advanced ICT features, to reduce significantly $TAE_{(l)(ts)}$, it might result that $TAE\_ICT_{(l)(ts)}$ becomes to be a negative number, due to the carbon emissions additions of these advanced ICT features.

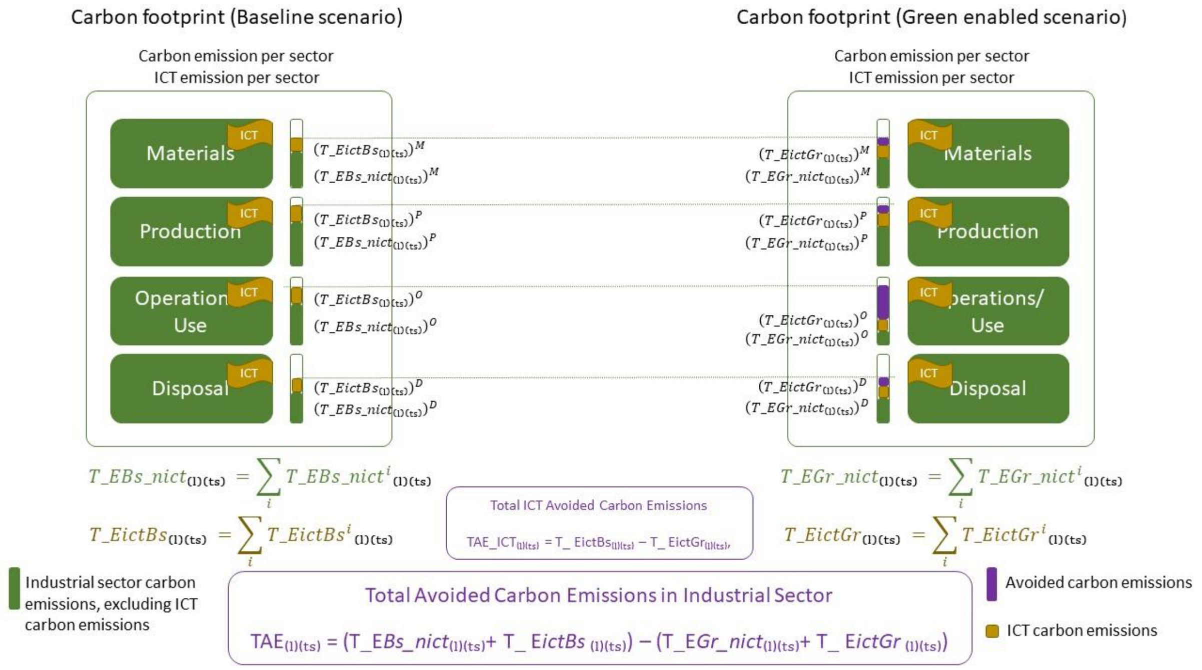


Figure 18: Visualisation of the Total avoided carbon emissions, with no circularity support when ICT is applied as an enabling technology, figure copied from (Alliance for IoT and Edge Computing Innovation 2023)

In order to derive the equation on calculating the avoided carbon emissions in an industrial sector, when ICT is used as an enabling technology, the following assumptions are considered:

- When ICT solutions are used to reduce carbon emissions in Industrial sectors, it is assumed that in the Use/Operation LC phase the carbon emissions are measured under a certain Load and for a certain type of service;
- Load = data processed by the network during a unit of time, e.g., 1 week, 1 month, 1 year;
- TS = Type of Service (follow the 5G type of services, e.g., Ultra-Reliable Low Latency Communications (URLLC);
- LCA = Life Cycle Assessment composed by Life Cycle (LC) phases Materials, Production, Use/Operation, Disposal;
- Unit: kgCo2e.

Appendix 4: Detailed life cycle inventory (LCI) of the ICT equipment used in the Living Labs

Below is the LCI for a LoRa gateway. The first tables pertain to the "subprocesses" or components that can be found in a LoRa gateway, such as the compact LoRa gateway, cabling, power over ethernet, and antenna. Table 26 shows the LoRa gateway process complete with the required subprocesses, and Table 27 shows the inclusion of the LoRa gateway in a preliminary inventory for LL1. The latter includes also the use phase of the LoRa gateway for one year, seen as the electricity use using the Luxembourgish residual mix. Use phase data for all ICT inputs will be included in the LL activities.

Sub-components of LoRa gateway

The following tables describe the inputs needed for the manufacturing of LoRa compact gateway, Power over ethernet, LoRa antenna 9dBi, LoRa gateway cable and Antenna mount bracket.

Table 21: LCI data for the manufacturing of LoRa compact gateway

Flows	Amount	Unit	Ecoinvent dataset
Inputs			
Electronics	0.8	kg	market for electronics, for control units {GLO}
Aluminium	0.4	kg	market for aluminium, cast alloy {GLO} + metal working, average for aluminium product manufacturing {RER}
Stainless steel	1.2	kg	market for steel, chromium steel 18/8 {GLO} + metal working, average for chromium steel product manufacturing {RER}
Polyethylene	0.1	kg	market for polyethylene, high density, granulate {GLO} + injection moulding {GLO}
Polycarbonate	0.5	kg	market for polycarbonate {GLO} + injection moulding {GLO}
Output			
LoRa compact gateway	1	piece	

Table 22: LCI data for the manufacturing of Power over ethernet

Flows	Amount	Unit	Ecoinvent dataset
Inputs			
ABS co-polymer	0.1	kg	market for acrylonitrile-butadiene-styrene copolymer {GLO} + injection moulding {GLO}
Stainless steel	0.06	kg	market for steel, chromium steel 18/8 {GLO} + metal working, average for chromium steel product manufacturing {RER}
Copper	0.4	kg	market for copper oxide{GLO} + market for wire drawing, copper {GLO}
Output			
Power over ethernet	1	piece	

Table 23: LCI data for the manufacturing of LoRa antenna 9dBi

Flows	Amount	Unit	Ecoinvent dataset

Inputs			
Fiber glass	0.193	kg	market for glass fibre {GLO} + injection moulding {GLO}
Polyester resin	0.055	kg	market for polyester resin, unsaturated {GLO} + injection moulding {GLO}
Copper	0.138	kg	market for copper oxide{GLO} + market for wire drawing, copper {GLO}
Tetrafluoroethlyene	0.138	kg	market for tetrafluoroethylene {GLO} + injection moulding {GLO}
Brass	0.028	kg	market for brass {RoW} + market for casting, brass {GLO}
Output			
LoRa antenna 9dBi	1	piece	

Table 24: LCI data for the manufacturing of LoRa gateway cable

Flows	**Amount**	**Unit**	**Ecoinvent dataset**
Inputs			
Cabling	0.1	kg	market for cable, unspecified {GLO}
Stainless steel	0.1	kg	market for steel, chromium steel 18/8 {GLO} + metal working, average for chromium steel product manufacturing {RER}
Output			
LoRa gateway cable	1	piece	

Table 25: LCI data for the manufacturing of the antenna mount bracket

Flows	**Amount**	**Unit**	**Ecoinvent dataset**
Inputs			
Aluminium	0.3	kg	market for aluminium, cast alloy {GLO} + metal working, average for aluminium product manufacturing {RER}
Stainless steel	0.3	kg	market for steel, chromium steel 18/8 {GLO} + metal working, average for chromium steel product manufacturing {RER}
Output			
Antenna mount bracket	1	piece	

LoRa gateway assembled

The table below represents the assembling of the previous components to obtain the LoRa gateway.

Table 26: LCI data for the assembling of the LoRa gateway

Flows	**Amount**	**Unit**	**Ecoinvent dataset**
Inputs			
LoRa compact gateway	1	piece	See Table 21
Power over ethernet	1	piece	See Table 22
LoRa antenna 9dBi	1	piece	See Table 23
LoRa gateway cable	1	piece	See Table 24
Antenna mount bracket	1	piece	See Table 25
Output			
LoRa gateway	1	piece	

LL1 preliminary ICT inventory

The following table illustrates preliminary LCI data for the modelling of ICT components in LL1. Data will be completed and updated based on data provided by LL partners.

Table 27: Preliminary LCI data for the yearly ICT usage in LL1

Flows	Amount	Unit	Ecoinvent dataset
Inputs			
LoRa gateway	1 / lifetime	piece	See Table 26
Weather station	2 / lifetime	piece	Datasets under development
Soil station	2 / lifetime	piece	Datasets under development
Electricity (use phase)	N.A.	kWh	market for electricity, low voltage {LU}
Output			
Yearly ICT usage	1	year	