MARVIC
MRV for carbon farming

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MARVIC (Meta)Data catalogue and guidance on '4R' principle in MRV

MARVIC

Deliverable 2.2

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Executive Summary

The **efficient and effective use of data is the backbone of any MRV system** or application. Both in reliability and quality of the outcome, as in the efficiency and costs associated with reaching this outcome. In this deliverable we explore the relevance and need for adequate data for MRV, introduce the MARVIC metadata catalogue that aims to facilitate easier and more effective search for and discovery of datasets for MRV and elaborate how the 4R principle (Right source, Right rate, Right time, Right place) often used in for example fertiliser management can be applied in the context of selecting data for MRV for soil organic carbon in an efficient and effective way.

The deliverable is relevant for anyone involved in or interested in finding, selecting or providing data for MRV applications or other spatial projects, from the local to the European scale. These include MRV operators, land managers, advisors, researchers and governmental organisations.

A **metadata catalogue** facilitates the easier discovery of data, knowledge and information resources by collating metadata from a variety of sources in a single location with added search functionality. In the MARVIC project, we have deployed an open metadata catalogue using existing open-source software, current metadata standards, and have **customised** this catalogue specifically **for MRV applications**. To this purpose we have translated the 4R principle used in fertiliser management to data for MRV applications by creating the **4 categories of Right Data source, Right MRV use, Right quality and Right Resolution**. For each category the meaning in the context of MRV applications is elaborated and its application in the metadata catalogue is described.
For some of the R's this is reasonably straightforward and the application can be facilitated by customised filters on keywords in the metadata. For others, the general application principles are described but further facilitation by semi-automation is difficult, since the data requirements following the application of the 4R principles are quite MRV project dependent and the quality and content of the metadata does not always allow automation.

A general conclusion of this work is that a **domain specific metadata catalogue** and **domain specific elaboration of data selection principles** can be beneficial to the domain community. However, a **limiting factor at present is the quality and completeness of metadata annotation**. Thus, continued attention, awareness raising,

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and capacity building on the topic, for example in the context of the Mission Soil, the Carbon Removals and Carbon Farming (CRCF) Regulation and the wider MRV community is important. This includes the development of domain specific terminology and the transposition of this terminology to machine readable vocabularies to facilitate metadata and data annotation to such an extent as needed for efficient and effective MRV applications.

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Abbreviations and Acronyms

CERIF	Common European Research Information Format
CF	Carbon Farming
CLMS	Copernicus Land Monitoring Service
CORINE	Coordination of Information on the Environment
FAIR	Findable, Accessible, Interoperable, Reusable
FMIS	Farm Management Information Systems
FSDN	Farm Sustainability Data Network
IACS	Integrated Administration and Control System
INSPIRE	INfrastructure for SPatial InfoRmation in Europe
LTE	Long Term field Experiments
LUCAS	Land Use/Cover Area frame Survey
MRV	Monitoring, Reporting, Verification
4R	Right Data Source, Right MRV Use, Right Quality, Right Resolution
EU	European Union
EJP SOIL	European Join Programme on Soil
ICOS	International Carbon Observation System
ISO	International Standards Organisation
DCAT	Data CATalogue
STAC	SpatioTemporal Asset Catalogue
WP	Work package
SOC	Soil organic carbon

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1. Introduction

1.1 Data needs in the context of MRV

In the context of Monitoring, Reporting and Verification (MRV) for carbon farming, data is used in every step of the MRV system, in different forms and for different purposes. Depending on the type of MRV system or purpose of the carbon farming project, its location, scale and other characteristics, the data requirements with respect to the minimum quality, accuracy, precision, resolution, scale, timestamp, format, and content of the data that is needed may vary considerably. Because of these differences in data requirements and the range in sources (Deroo et al., 2026, Vrot et al., 2026, Ceschia et al., 2025, Biffi et al., 2024, Biffi et al., 2026, Ofori-Karikari et al., in preparation) that are available to find these data, it is **not always easy to select the right data for a specific MRV application**. To facilitate the MARVIC project and possibly the wider MRV community, we have built a **dedicated MRV metadata catalogue** and venture to apply the **4R concept** used in other disciplines, like soil fertility management, to MRV, to examine if this can be useful. Application of this concept in the wider framework of MRV design as produced by MARVIC, is described in Lanckriet et al. (2026), which will be published at the end of the project.

1.2 The relevance of a dedicated (meta)data catalogue for MRV

Metadata is data about data. In other words, it describes the characteristics of a dataset, database, map, report, article or other knowledge source in such a way that a potential user can understand how the data or knowledge was derived, made, collated or compiled, what it contains, who made it, when it was made and if it is derived from or related to another source. Ideally, all datasets and knowledge sources have associated metadata, described according to common metadata standards, that is fit for the most common re-uses of the data or knowledge sources and is openly accessible. In many cases, the access or re-use of datasets itself may be restricted, but their metadata is freely visible, accessible and published in data repositories, catalogues or other online platforms.

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The **accessibility and characteristics of metadata allow a structured analysis of the suitability of datasets or knowledge sources for specific MRV applications**. However, metadata is not always provided in a systematic and standardised manner, and many of the metadata is dispersed on various online or local platforms, limiting its findability and use in this structured analysis. In addition, many platforms are designed in a generic way to facilitate many different domains, beyond even geographical applications, which may result in limited search options for domain specific applications. A domain specific metadata catalogue that compiles metadata relevant to MRV applications from multiple sources inside and outside of the project, and which facilitates MRV specific searches is therefore **of added value to MARVIC** and to the MRV community as a whole. It offers a single online location for looking for MRV relevant datasets, allows to search on predefined MRV relevant filters, and can be a source of inspiration, knowledge and data exchange between MRV actors, while providing links to the actual data and knowledge resources, stored on open or closed persistent repositories.

An example of such a metadata catalogue is available on the Impact4Soil platform[1] (Vrot et al., 2026) where it is integrated in a broader platform that also showcases examples of maps, practices, and a networks search function, etc. The difference between the Impact4Soil catalogue and the MARVIC catalogue[2] is the geographical scope (global versus mostly European), the focus on all knowledge sources versus mainly geographical data, the possibility to include MARVIC specific datasets and as such service the project specifically, and to apply a more extended and dedicated search functionality. In time, it is foreseeable that the two catalogues harvest from each other or collaborate even more.

1.3 Structure of the deliverable

This deliverable aims to provide a description of the added value and reasoning behind organising MRV metadata for the MARVIC project in **Chapter 1**. Followed by a description of the design and process of adding content to the metadata catalogue (https://marvic-catalogue.containers.wur.nl/) in **Chapter 2**, and an explanation of the 4R concept applied to MRV and in particular the metadata catalogue in **Chapter 3**. In **Chapter 4**, the embedding of the work in the project and after project outlook is

[1] https://www.impact4soil.com/
[2] https://marvic-catalogue.containers.wur.nl/

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described. MARVIC deliverables related to this deliverable are: Assessment of accessibility and interoperability of farm data for MRV systems throughout Europe (**D2.7**, Deroo et al. (2026)), Open source datasets of benchmark sites (**D2.1**, Biffi et al. (2024), Benchmark site guidelines (**D2.3**, Biffi et al. (2025)), Remote sensing solutions for MRV (**D2.5**, Ofori-Karikari et al. (2026, in preparation)), Draft MRV framework (**D1.3**, Lanckriet et al. (2026)) and Model catalogue (**D3.2**, Miranda Oliveira et al. (2026)).

2. Metadata Catalogue

2.1 Aims and guiding principles

The metadata catalogue[3] in the MARVIC project aims to be a sourcebook, one online location where it is easy to find project and non-project resources on all aspects of MRV that need data. It creates a platform where project partners and other potential users can search and find datasets produced by others and evaluate if they are fit for the purpose for which they are in need of data for. Another aim is to showcase the produced and available data so the reuse of project data is promoted, which can be beneficial for data owners.

One of the **guiding principles** in designing the metadata catalogue is that it needs to be **customised to MRV workflows** and meets the needs of the MARVIC project. To this end, the catalogue, its functionality and customization have been discussed at all annual project meetings to understand project needs and aims to address all standardised steps in the MRV framework to the extent of which it is relevant to the catalogue functionality. Although development is still ongoing on the catalogue, the final version may not satisfy all possible situations of MRV data needs, which tend to differ in different land uses, regions and soil types, but it can attempt to address the main ones. Presenting the catalogue at these meetings and during webinars has also raised the awareness within the project that the catalogue is being developed and can be a useful tool.

Another guiding principle in designing and setting up the metadata catalogue is that the **metadata and ideally also data it refers to is FAIR: Findable, Accessible, Interoperable, and Reusable**. Which means that metadata should be as complete as possible, that standardised keywords are used to characterize the data (ideally from

[3] https://marvic-catalogue.containers.wur.nl/

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online vocabulary repositories such as AgroVoc, GEMET, etc. and/or dedicated glossaries, e.g. MARVIC (Photinodellis et al., 2026)), that a data usage license is present, the title of the metadata records is meaningful, etc. To this purpose we choose to use standards where available and applicable; we have adopted the ISO19139 metadata standard, provided back-end mapping for other metadata standards, are in support of the ongoing MARVIC effort to develop a project glossary and use online vocabulary repository terms, and actively collaborate with SoilWise project[4] until the end of the project to enhance this. This will allow the metadata to be easily integrated into other metadata platforms through harvesting, and as such also enhances its FAIRness.

Another guiding principle for the catalogue is to use **easily customisable, lightweight open-source software** and to **build on experience and tools developed** in other (EU) projects such as EJP SOIL. On the one hand, this allowed to quickly deploy a first version of the catalogue early in the project, to not re-invent the wheel and to be efficient. On the other hand, it allows other projects to build on specific developments of the software or its implementation in the project, during and after the project ends, making the tools more sustainable.

Both software and metadata records are and will until the end of the project be **deposited in a persistent online repository** at regular intervals (software: https://doi.org/10.5281/zenodo.20306323, metadata: https://doi.org/10.5281/zenodo.20306053) and at the end of the project. The catalogue is harvested by the SoilWise metadata catalogue and in case the catalogue will be deprecated or moved to a different project like CAFAMORE, the harvesting can be changed to a harvest from the persistent repository storage. In this way, the after-project sustainability is ensured.

2.1.1 *Metadata standards and keywords*

Metadata standards provide a structure and a common list of characteristics that describe a dataset or knowledge source. Because they are organized as a structure, they are machine-readable, easily searched, indexed and stored. There are several common metadata standards, each developed for a specific purpose and in use by a

[4] https://soilwise-he.eu/

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specific target group. The ISO19139[5] is comparable to the INSPIRE metadata standard[6] and is mostly used in academia or research and also in governmental reporting. DataCite[7], DCAT[8] and Dublin Core[9] are other common metadata standards (see **Table *1***), of which Dublin Core is often seen as a minimum list of metadata items that is the core of many of the other standards. Many of the items in different metadata standards are mappable to each other, which is used in the MARVIC metadata catalogue as well (see Chapter 2.2). The format in which the metadata standard is implemented and therefore in which the metadata is stored can differ (e.g. json, yaml, txt, xlsx or other) but these can be converted from one format to the other as well if needed.

In MARVIC, we have chosen to **apply the ISO19139 metadata standard** as it is the most elaborate and most commonly applied in the community we aim to address: the research and possibly wider community.

Table 1: overview of metadata standards and tools per community

Community	Metadata format	Metadata tools
Academia	DataCite (DOI)	Dataverse
Open Data/ Semantic Web	DCAT	CKAN, BRegDCAT
Geospatial/ INSPIRE	ISO19115:2003, ISO19139	GeoNetwork, ArcGIS, QGIS, pycsw
Earth Observation	STAC[10]	STAC browser
Search engines	Schema.org	Rich results test

For several of the metadata fields indicated in the standard, it is advisable to use (semi-) standardised and/or restricted entries. This is the case for the data usage licenses, where we promote the use of Creative Commons licenses[11] where possible, and attempt to standardise the more custom licenses that are present in the project due to national or legacy data restrictions.

This is also the case for the use of keywords that are assigned in the metadata to the data by the data owners. **Keywords are crucial** to help users find datasets and to help them evaluate the content of a dataset and judge if it is fit for purpose for their intended use. Users use (MRV specific) filters or enter keywords in the search bar to find datasets.

[5] https://knowledge-base.inspire.ec.europa.eu/publications/technical-guidance-implementation-inspire-dataset-and-service-metadata-based-isots-191392007_en
[6] https://knowledge-base.inspire.ec.europa.eu/metadata-technical-guidelines_en
[7] https://datacite.org/
[8] https://www.w3.org/TR/vocab-dcat-3/
[9] https://www.dublincore.org/specifications/
[10] https://stacspec.org/en
[11] https://creativecommons.org/

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This means the same keywords used in the filters, or that users commonly type into the search bar should be present in the keywords of the metadata records that need to be found. This not only holds true for the MARVIC catalogue, but for any (meta)data repository.. If the keywords use terminology that is commonly agreed upon by the community, and if all such terms that characterize the dataset are used in the metadata, and if these terms coincide with the terms users use to search for or filter the data, then this becomes a very powerful way to find datasets and increase the possibility of reuse.. Although search algorithms can be pointed towards searching not only the keywords fields, but also the title and abstract fields and possibly other metadata items, the results may be more concise if standardised keywords are used.

During the annual project meetings where the catalogue was discussed, we have repeatedly discussed with the consortium on the main categories and keywords that describe these categories, to ensure that these are the **main and commonly understood keywords by the consortium for MRV application**. These have subsequently been set as filters to allow easy search in the catalogue. The MARVIC glossary effort further supports this project alignment on terminology and can be leveraged in the annotation of metadata records by project-standardised keywords. We furthermore support the proposal by the SoilWise project to apply a hierarchy in the use and creation of new vocabularies (defined as (online machine readable) community accepted terminology), in which legislatively defined terms are preferred, followed by community standardised terminology (e.g. for soil description, soil classification, soil lab methods), de facto standards used in the community, and literature or specific project based terminology. Together with SoilWise we are still working on making the MARVIC glossary machine readable, which will make it easier to apply rigorously in metadata annotation. At the same time, we are in the process of assigning the filter keywords to the metadata resources in the MARVIC metadata catalogue. This will still need to be verified by MARVIC partners to the extent it relates to MARVIC datasets (see also **Chapter 2.2**).

2.2 Technical architecture and customisation options

A metadata catalogue **consists of several (technical) components**: the metadata records itself that are typically stored in a database, a front-end that allows to display and search the records, and a workflow to harvest the metadata records, standardise them, store them in the database, and make them available for the search algorithm.

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For the MARVIC metadata catalogue, the EJP SOIL metadata catalogue software described in EJP SOIL D6.6 (van Genuchten et al., 2024) and in EJP SOIL D6.8 (van Genuchten et al., 2025) was used. This consists of an interface of OGC-API – Records API with HTML encoding, and an application of pycsw (https://pycsw.org) that operates on a PostGres database that contains records harvested from a Git repository (https://git.wur.nl/grp-marvic/marvic-catalogue). The git repository is populated by several sources, detailed in **Chapter 2.3**. These can be extended until the end of the MARVIC project if this is considered useful for the project and the community.

Upon upload or harvesting, the metadata (that can also be supplied in DataCite, DCAT or Dublin Core) is standardised and transformed to the yaml format and the ISO19139 standard in git. It is subsequently stored in the PostGres database to allow the pycsw application to search and display the results. All software modules are open source (MIT license). The software components are described in more detail in the EJP SOIL D6.6 and D6.8 deliverables (van Genuchten et al., 2024, 2025).

The **technical architecture was taken mostly as is**, and the efforts in the MARVIC project consist of **customizing the catalogue for the MARVIC and the larger MRV community**. This consists of surveying on which datasets the metadata catalogue should serve metadata to suit the aims of the MARVIC project, as was done during annual meetings and meetings with relevant task and WP leads. The other customization towards MRV use cases was designing and applying MRV specific filters according to the process described in **Chapter 2.1.1**. This resulted in the following filters:

Spatial scope
> Local
> Regional
> National
> Europe

Landuse
> Agroforestry
> Arable
> Grassland
> Mixed
> Peatland
> Semi-natural

Theme

> Administrative-units

> Soil

> Atmospheric-conditions

> Land use

> Orthoimagery

> Farm-management

> Crop

Monitoring networks

> LTE

> EC-flux-site

> Farm-monitoring-sites

> National-monitoring-sites

Type

> Dataset

> Model

> Series

> Service

> Software

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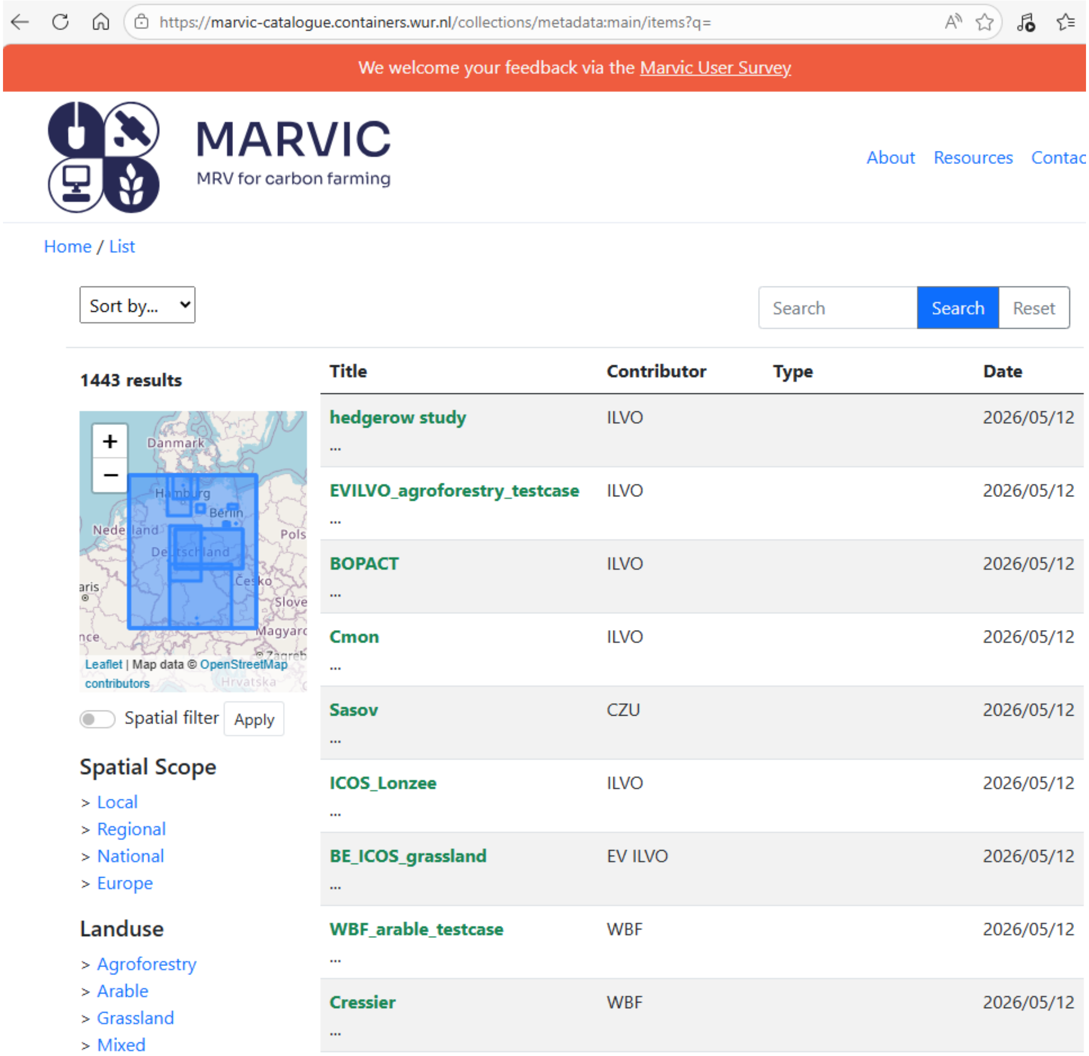

Figure 1: screenshot of MARVIC catalogue search environment (dd 17 May 2026)

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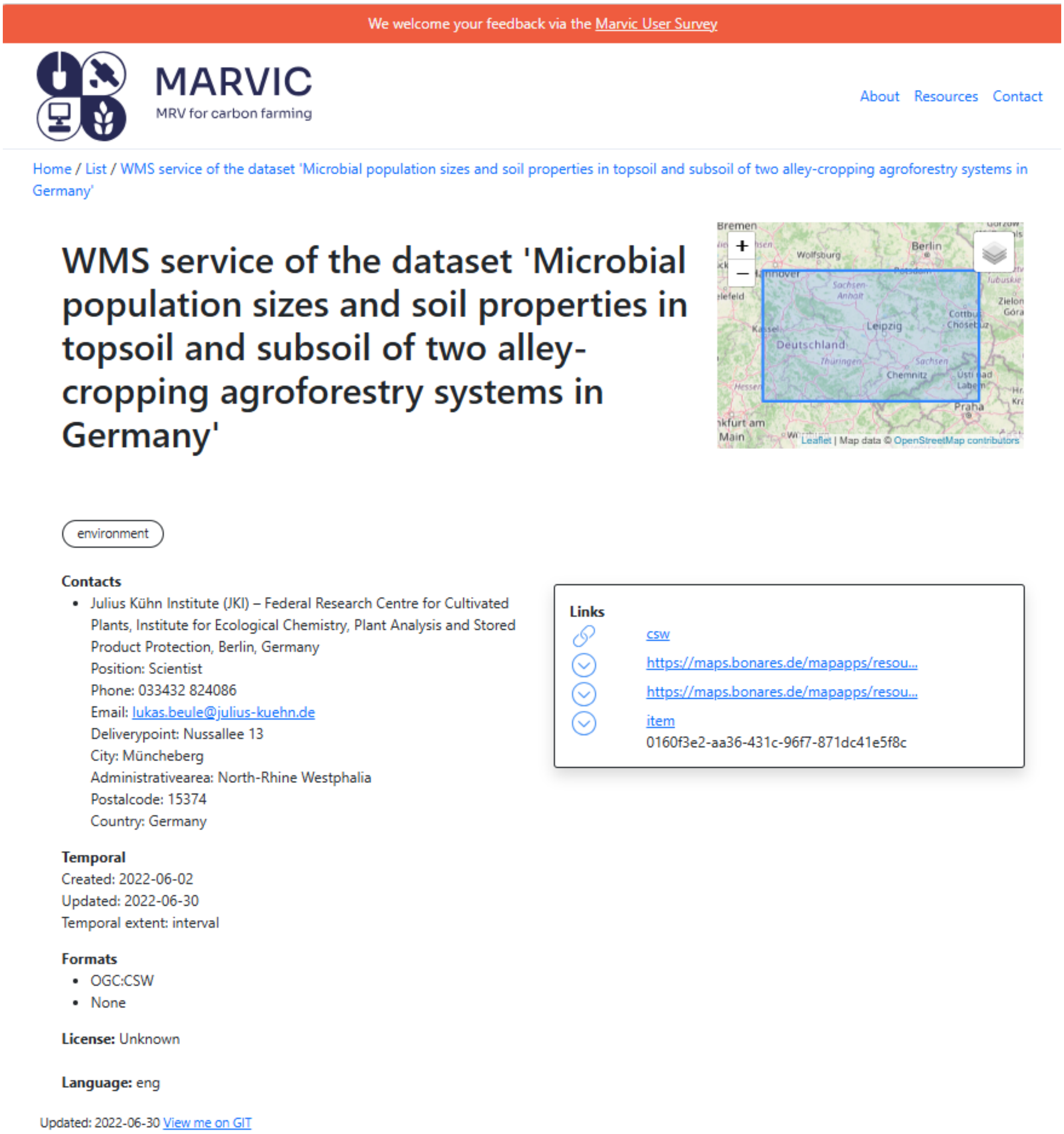

Figure 2: screenshot of metadata record in metadata catalogue as example (dd 17 May 2026)

To assess the functionality of the catalogue several project partners have **tested and evaluated** the functionality of the MARVIC metadata catalogue. Several issues were raised, like unclear titles, missing or very bespoke license information, not all available metadata is displayed in the catalogue, the time period the dataset covers beyond the information on most recent update of the dataset, etc. Several of these have been addressed, others are still in progress, and others will remain active until the end of the project since they relate to possibly new incoming datasets and usages.

Several of the issues raised are not necessarily related to missing functionality, but to failing functionality due to incomplete, non-standardised or too project-oriented metadata. For example, the use of codes to indicate MARVIC benchmark sites in the titles of metadata records. This means project partners understand the titles, but years after the project they will possibly not, and potential other users might not understand either. Or the use of keywords that do not coincide with the project defined keywords that are used as filters. This results in a filter yielding no search results in the front-end, while there are relevant records available, that are just not annotated correctly.

For these **raised issues** (related to titles, usage licenses, keywords) it is usually good practice to ask the data owner to update these according to provided guidelines. Although this is a preferred process, we have chosen to propose adjusted titles, standardised licenses and additional keywords to the MARVIC data owners and test case leads per metadata record. They are then asked to verify if the proposed changes are correct given the content and characteristics of the dataset (either their own or one they are familiar with), after which they are updated in the git repository and become visible in the catalogue (and the metadata records that are deposited in a persistent repository at the end of the project). We believe this process is faster and will yield more complete and standardised results. This process is still ongoing and is expected to be completed before autumn 2026.

2.3 Content of the catalogue

A main aim of the catalogue is to **provide potentially useful metadata** for project partners and other MRV users upon which they can apply the 4R principle to find the data that is useful for their purpose. Based on this aim we selected at least three sources that would be useful to include and harvest on a regular basis to the git repository that provides the content of the metadata catalogue:

- MARVIC metadata collated by T2.2 on the Benchmark sites (Biffi et al., 2024), T2.5 on farm data sources (to be added before July 2026) (Deroo et al., 2026);
- EJP SOIL metadata records of national soil data repositories (stocktake EJP SOIL D6.1 (van Egmond et al., 2021)) harvested from the EJP SOIL git repository;
- Other potentially useful repositories. At present at least the BonaRes[12] and ESDAC[13] repositories were identified and harvested, respectively containing metadata from Long Term Field Experiments and European-wide datasets

[12] https://tools.bonares.de/ltfe/
[13] https://esdac.jrc.ec.europa.eu/

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produced by ESDAC and others. From the EJP SOIL catalogue the research based records that are directly relevant for MRV applications were selected manually and added to the MARVIC catalogue through harvesting as well. This can be extended upon request.

Although these are useful datasets for MRV purposes, it is for sure **not an exhaustive list**. There are for example more LTE datasets, the forestry national datasets may not always have been included in the EJP SOIL national datasets, commercial MRV data is not included, there may be other research data that is not found and added yet. When the keywords standardisation effort as described in **Chapter 2.1.1** is further along, a dedicated search in the SoilWise project catalogue may yield additional useful metadata of MRV datasets that can be harvested to the MARVIC metadata catalogue with a dedicated query to the SoilWise API.

Other additional **data sources can be added** and updated until the end of the MARVIC project if this is considered useful for the project and the community. An example are the results on European mitigation potential maps which are expected to be included in the catalogue as well as soon as they are published.

At the time of writing this deliverable (end of April 2026) the catalogue contains 1443 metadata records. The number of MARVIC Benchmarks sites is 74 of which 14 on agroforestry, 6 on peatland, 13 on grassland, and 41 on arable. The EJP SOIL stocktakes of national soil data sources (incl. the information provided by the JRC through the MensMeu survey (EJP SOIL D6.1 (van Egmond et al., 2021)) are available in the catalogue consisting of 389 records. About 30 datasets from EJP SOIL research that are considered useful for the MARVIC community are available, as well as about 841 records of the BonaRes repository. From the ESDAC repository 109 datasets are available.

Table 2: Overview of the content of the MARVIC metadata catalogue on 30 April 2026

Source	Nr of records
MARVIC Benchmark sites	74
Agroforestry	14
Peatland	6
Grassland	13
Arable	41

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National datasets	389
ESDAC datasets	109
EJP SOIL research	25
BonaRes	824

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3. Suitable datasets for MRV: the 4R principle

3.1 The 4R principle and its relevance to MRV

In fertiliser and soil fertility management, the 4R principle is a common approach towards effective and efficient application of fertilisers for crop growth. It consists of selecting the **R**ight source or type of fertiliser for the needs of the crop, to apply this fertiliser at the **R**ight rate, so the amount of fertiliser per surface area, at the **R**ight time in the crop growth cycle, and at the **R**ight place, right where it is reachable by and available to the crop. This is illustrated in Figure 3.

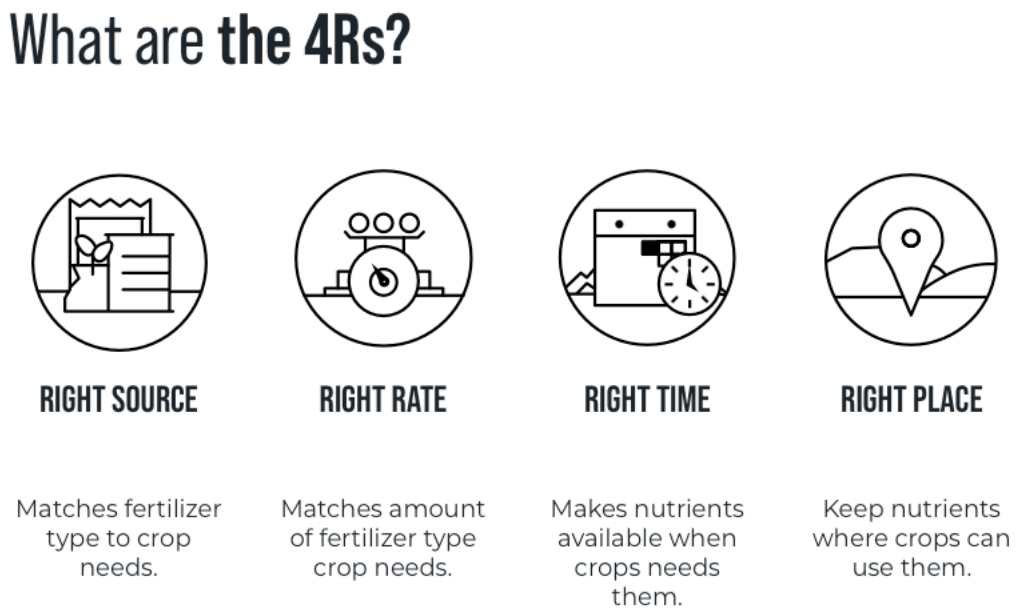

Figure 3: 4R principle in crop fertiliser management (source unknown)

For monitoring, reporting and verification applications, for example for soil organic carbon, it is also important to be efficient and effective, in the design of the framework, project or application, but also specifically with finding and using data to enable the application of the MRV. To this end, we have **redesigned the concept of 4R** as used in fertiliser management to the MRV data for carbon farming. This results in the 4R's of identifying the **Right data source**, for the **Right MRV use**, with the **Right data quality** and at the **Right data resolution**. These are 4 cornerstones of the efficient use of data in MRV since they ensure the data is usable, applicable and facilitates the operation of the MRV, and at the same time allows to protect the MRV application against over

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dimensioning of the data collection effort by not requesting data qualities or very high resolutions that have no added value for the MRV system.

Each of the R's is explained in more detail in the remainder of this chapter, including the way it is implemented in the metadata catalogue.

3.2 Right data source

The R of the Right data source pertains not necessarily to the physical or online source location of the data, but to the **type of data source that is needed** for a specific MRV application. The **reliability** of a data source or dataset contributes to the assessment if the data is fit-for-purpose, just like for example the quality, content and spatial extent of the data. The reliability of the data often relates to the type of data source that is selected. We identify a sequence, or a **hierarchy in data sources**, that starts with sources of high reliability in which data can be used with only minimal checks, going down to potentially quite useful sources which however require a check of the reliability of each dataset.

The most reliable data sources are authoritative data sources. These are typically compiled or collected by trusted, institutional or governmental sources and have a system of data validation and curation in place. The data is regularly updated, well documented, available with clear license conditions or open and on well-known and persistent repositories. The spatial coverage is typically quite large, although resolution or detail at smaller scales may be less. Examples are the LUCAS Soil monitoring data available at ESDAC, the IACS or FSDN land management data, the Copernicus Land Monitoring Service (CLMS), CORINE land cover, national soil monitoring systems, etc.

A second type of data source are well established trusted sources but without necessarily institutional backing. They have a peer review process in place, the data is reasonably well described and the metadata is accessible, the availability of the data itself varies. Examples are known repositories of LTE networks, ICOS flux sites, scientific literature.

A third type of data source are data from Farm Management Information Systems (FMIS) and private companies. This data is often quite detailed and extensive, and depending on the rigour that is applied by the data collector can either be quite good, detailed, well documented and trustworthy. Or it can have gaps in time, space and content, limited to no annotation and accessibility or it can be closed and not available altogether. Often a

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data review process or curation is not in place and this data will need to be checked and evaluated for reliability and quality on a per dataset basis.

A fourth category of data sources that we distinguish is so called grey literature. This can consist of websites, short communications, video’s etc. mostly containing knowledge. The reliability of these sources varies per source and is often local or regional or for very specific applications. Per knowledge item or source the reliability of the information should be evaluated to determine if the knowledge is fit for purpose. Due to its local nature, it can be very targeted and valuable, since it is based on local knowledge, but the scientific underpinning of the knowledge is not always clear.

When determining which type of data source is fit for purpose for a given application, it can be useful to consider the minimum and the desired reliability the data should have to still enable the application. If more reliable data is available it is usually advisable to use these sources if applicable, or to localise or specialise these more reliable sources with less reliable sources if needed. It is also advisable to always check the reliability of a dataset before applying it, by doing some explorative data analysis and cross-checks to ensure the data is correct. An example can be to check the reported soil organic carbon content of a sample or field against the reported organic matter and other soil properties to see if it falls within expected soil organic carbon ranges.

An interpretation of the Right data source can also be a source that contains the type of data that is needed for a certain MRV application. This is a valid interpretation, but here we have added this applicability of the dataset to the Right MRV use.

3.2.1 *Implementation in Catalogue*

In the MARVIC metadata catalogue we have enabled the selection of data sources according to reliability, or Right data source in two ways. The first is by listing the Contributor or data provider on the main search results page in the second column, right next to Title. With this information, users can judge in which data source type category the dataset falls by evaluating the source themselves.
In addition, the Spatial Scope and Monitoring Networks categories in the filters section, containing respectively the filters National and Europe, and the section Categories of benchmark sites, including LTE, EC-flux-site, Farm-monitoring-site and National-Monitoring-Sites, further assist the user in filtering for the data source type needed for the application. We could define more filters to help select the data source type, but

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this is only advisable if the metadata in the catalogue is annotated with the keywords of these filters. Otherwise the additional filters would not yield any results.

3.3 Right MRV use

The need and use of data in an MRV application can be quite diverse and can e.g. range from the need for information about a field or area to apply smart soil or biomass sampling for monitoring or verification, or for spatial soil organic carbon data to validate a baseline, calibrate a model etc., relating to several subtopics in Monitoring, Reporting and Verification. To assist in understanding the application of the data in the MRV and the subsequent requirements to e.g. quality, resolution, reliability, content etc., it can be useful to **categorise the possible MRV uses**, and then to check whether the available data meets these needs. A first categorisation which is mostly focussed on MRV use can be:

- Model calibration/parametrisation
- Model validation
- Model input
- Baseline determination
- Sampling
- Verification
- Reporting

However, these MRV uses are quite specific for MRV applications, and datasets may not often be annotated with these keywords, since they are often collected for a wider range of applications, also outside of the MRV domain. In addition, the requirements that the MRV uses pose to the data in each category can vary per application and data can be useful for multiple categories. Therefore, we propose that users determine the foreseen MRV use, for example according to the above list of uses, and subsequently determine the criteria that these pose to the data sources they need. These can then be translated into specific search terms that assist in locating and evaluating the data.

This **applicability** of a dataset for a certain MRV use also relates to the **content of the dataset, the spatial and time period coverage**, field and lab protocols used etc.. An approach to systematically judge the need for additional data collection that can also be used to evaluate if a dataset is fit-for-purpose regarding content and coverage, is given in Knotters et al. (2018, 2019). This approach evaluates for example the target universe, variable, parameter, quantity, the domain of interest and type of result. It also provides some pointers on accuracy measures and requirements related to the Right quality (**Chapter 3.4**). Conversely, if a new or additional dataset needs to be collected for the MRV application to proceed, the same criteria as listed by Knotters et al. (2018, 2019) can of course be applied to define the additional data need.

Content and coverage specific search terms may be very similar to or the same as the topics of the other R's, but we can specify a list of data content types that may assist in this more detailed specification of data needs:

- Soil data
- Biomass data
- Crop/ land use data
- Activity data
- Climate data
- Administrative boundaries

When using this second list of categories in addition to the specific and often very dedicated data needs related to the MRV use, users may narrow down the search and can judge the degree to which data is fit for purpose according to the foreseen MRV use based on the abstract or description in the metadata, the keywords, a preview, etc. The same data source may also be used for different MRV uses in different MRV applications. In general it is advisable that the datasets used in an MRV application, including for which MRV use they are used, are well documented to make sure the same dataset is not used e.g. both for calibration and validation of a model or application. If documentation is done correctly, the re-use of a dataset for multiple (different) MRV applications does not need to be a problem and can even be an advantage, since data collection or compilation, standardisation efforts do not need to be duplicated for each MRV application.

3.3.1 *Implementation in Catalogue*

Implementing the first list of MRV uses in the MARVIC metadata catalogue for example as filters, keywords or labels has been considered but is deemed very difficult in a generic way, due to the very specific needs for each MRV application. This would require evaluating all metadata records in the catalogue and labelling these to possible MRV uses by assigning the (multiple) applicable categories as keywords to each record. Not only is this prone to errors since the people that do the annotation will not necessarily be familiar with the datasets, it can also hardly be automated, except in either a very crude

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way or with an AI approach for which more metadata records and reported MRV uses need to be available to be successful.

This is why at present we have decided to implement the second proposed list of data content types indicated in **Chapter 3.3** to facilitate finding the right data for the Right MRV use. In the filter section of the catalogue we have included a Theme category, that includes the mentioned content topics as filters. The terms are slightly adjusted for some topics to align with the AgroVoc[14] online vocabulary repository of standardised terminology. Administrative boundaries (a term more often used in MRV) is represented as Administrative-Units, and Climate is represented by Atmospheric-Conditions. Activity data is represented by Farm-Management, and Crop and Land use have been separated into two categories. For now Biomass data is represented by Orthoimagery, but this is possibly not ideal and may need to be renamed if project partners indicate it is counterintuitive.

3.4 Right quality

The **quality of a dataset** can be defined in many different ways, **either related to the data itself or to the metadata**. Typical qualifications of quality are:

- the quality of the data itself (its precision, accuracy, completeness);
- the availability of information about the uncertainty of the data;
- if the data has been peer reviewed or verified and by whom (linking to reliability in **Chapter 3.2**),
- the completeness of the metadata (e.g. the availability of a data usage license, data owner and contact, keywords, title, abstract, content information, data collection methods, units, etc. according to the metadata standards listed in **Chapter 2.1.1**);
- if standardised terminology is used in the metadata and the data model, for example following relevant standards in the domain and/or online vocabulary repositories;
- if the data model and possibly mappings to other (more) standardised models is provided;
- if the dataset is standardised or even harmonised to common data models such as INSPIRE, ISO28258, IACS, etc.

[14] https://www.fao.org/agrovoc/

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Ideally, a dataset should meet all of the above quality criteria, making it a FAIR dataset and making it easy to evaluate its suitability for the foreseen MRV application. Often however, a dataset will not meet all of the above criteria. Authoritative, curated and peer reviewed datasets will typically perform better (see also **Chapter 3.2** related to reliability), but this needs to be evaluated on a per dataset basis. In addition, some criteria are more relevant for the evaluation of the possibility of reuse of the dataset for a given MRV application, such as the completeness of the metadata and the quality of the data itself, while other missing quality aspects can be mitigated if needed, such as the standardisation of a dataset to a common data model.

Although many users typically would like the best possible dataset with the highest quality available, it is worthwhile to consider the **minimum quality** that is needed to allow the MRV application. This may enlarge the list of possibly suitable datasets, and thereby allow selection of datasets based on the other R's that together determine their applicability.

After evaluating the applicability of the wider range of datasets that satisfy all R's, the quality of the datasets that have been shortlisted can be assessed (again) and the dataset that is the best fit in applicability and quality can be selected. The list of quality criteria listed at the beginning of this chapter can be a guide towards high quality data collection, annotation and provisioning. More information on standards, methods and tools for soil information collection can also be found in a structured manner in van Egmond et al. (2023).

3.4.1 *Implementation in Catalogue*

The quality aspects as described in **Chapter 3.4** encompass many different aspects of data and metadata, most of which are reliant on the quality of the datasets and metadata itself as provided by the data owner. Some criteria can be evaluated in metadata records and added as a quality assessment functionality to the metadata catalogue, like the completeness of metadata, or by providing linked data sources or additional metadata fields for uncertainty information. Adding automated metadata completeness checks could be a good incentive for data producers to improve metadata, and will make it easier for users to assess the quality of the metadata. However, this metadata completeness functionality requires significant software development that is not foreseen in the project and is at present being carried out in the EU HE SoilWise project (GA 101112838).

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Adding additional metadata fields is possible, but not useful if data owners and providers do not provide the information to fill these.

Therefore, the main implementation of the Right Quality that we propose and implement in the MARVIC metadata catalogue is focussing on improving standardisation and online accessibility of MRV terminology (see **Chapter 2.1.1**), and on improved guidance and awareness of the usefulness of providing good quality data, through webinars about FAIR data as reported in milestone M2.1. This will for sure not solve the challenges of limited or faulty data annotation and uncertainty information assessment, but hopefully, it will be a step in the right direction and an incentive to data owners or providers to provide better quality data since it will increase the likeliness of reuse.

At the same time, we propose to evaluate the Right Quality of the data using the criteria stated in **Chapter 3.3** and **3.4**, both on quality and on applicability of data for a given application. Lastly, these criteria partially overlap with the descriptions of the reliability of datasets in **Chapter 3.2** since quality and reliability often go hand in hand. So applying the guidance on selecting the Right Data source will also improve the selection of data with the Right Quality.

3.5 Right resolution

The Right Resolution pertains literally to the resolution of data that serve as input data for an MRV application, and can also be understood as the scale, the geographic extent, or for example in the case of parametrisations for models or transfer functions, the geographic application domain.

Resolution refers to the grid size (usually in meters, e.g. 20 by 20 meters) of raster maps, while the **scale** of a map refers to the level of detail that is depicted on a polygon map, or the ratio between a centimetre on a paper polygon map and the actual distance in meters it represents (e.g. 1:50.000). **Scale** is also used to refer to the type of geographical coverage the data layer represents (e.g. local scale, regional, national, European scale, etc.). The **geographic extent** refers to the outer geographic boundaries that a data layer pertains to, usually linked to a specific place (e.g. a project area with outer coordinates indicated). The **application domain** relates to the area or the environmental characteristics for which the information is considered valid. This can be the same as the geographic extent, but often has less strict boundaries and can also refer to for example a land use, soil type, pedoclimatic zone, etc.

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When selecting data or information layers for an MRV application, all of these are relevant to consider. The geographic extent this is a binary condition: if the geographic extent of the data layer is outside of the area of the MRV application, then they are not usable for the MRV application. The application domain of the information layer is usually also binary, but when a data or information layer seems suitable otherwise, and no other potentially suitable information on the domain of interest is available a validation of the applicability in the wider or new application domain can be conducted to assess its suitability.

For the scale in the sense of geographic coverage, the scale of the data layer usually should at least be the scale of the MRV application or larger. For example, a national scale MRV application needs spatial data layers at least at national or European scale. Smaller scales can be useful when the geographic extent falls within the area of application of the MRV, but multiple of these data layers will then be needed to achieve the desired coverage, leading to data harmonisation or scaling challenges.

For resolution of gridded data and scale on a polygon map, a first consideration to assess the necessary (maximum suitable) resolution or scale is the foreseen MRV use and possible additional uses of the data. A spatially explicit map, for example of the soil organic carbon stocks, soil texture or pH variation on a field, can be used as input to a model that runs on pixel scale and also for precision soil management. An areal average, for example the average of soil organic carbon content of a field, can be used as input to a model that runs at field scale or for per-field soil management. When an input data layer is already aggregated or disaggregated to the field boundaries in this case, this limits the data preprocessing needed.

For both applications, the ***minimum*** **needed resolution for the MRV application** can be compared to the resolutions of the available data layers to evaluate which layers would be suitable. Starting from the minimum needed resolution should result in a larger list of data layers to select from, allowing to take the other R’s into account that are non-binary, such as quality. It is often tempting to choose the highest resolution data layer that is available. However, a higher resolution does not necessarily mean that the accuracy of the data layer is higher. It can even be lower depending on the methods used, and a higher resolution can therefore create a false sense of accuracy. Since the estimated values on a map are aggregated or averaged to the size of the grid cel, this typically removes and averages out any variation in the mapped variable (such as soil properties or biomass measurements) that occurs within the grid cel. However, not only the values of the target variable smoothen, but also the error smoothens or averages out. It can therefore be advisable to use a coarser map or to aggregate to a coarser resolution, if the accuracy is more suitable for the MRV application and the resolution is still acceptable.

3.5.1 *Implementation in Catalogue*

For the implementation of the Right resolution in the metadata catalogue we need to address all possible interpretations of Right resolution as described in **Chapter 3.5**. The scale in the sense of geographic coverage is addressed by adding a set of filters grouped under Spatial Scope, with the filter options Local, regional, National and Europe. The filters in the group Monitoring Networks also allows filtering to data sources of a relevant (geographic) scale. Both groups of filters allow easy filtering since most datasets are labelled with these terms. For the records without these keywords, we aim to assign these terms to the majority of the current metadata records before autumn 2026 according to the procedure described in **Chapter 2.2**. The application domain can be selected by choosing the appropriate filters from the Landuse and the Theme filter groups.

The geographic extent of possibly suitable datasets can be evaluated using the spatial search box on the top right of the overview page of the catalogue. If metadata records indicate the geographic extent of the pursuant dataset, the blue bounding box allows easy identification, including zoom functionalities of the datasets. A drawback here is (again) that the usability of this functionality depends on the presence of this information in the metadata, and therefore on the quality of the metadata.

Quick and easy identification of the Right resolution and scale as related to polygon maps in the catalogue is more challenging, since this is not a standard metadata record field in the adopted metadata standard. Hence this type of information should be provided in the description or abstract of the metadata record, but this is often lacking. Another option at least for the resolution of gridded data is to extract the resolution automatically from the data layer itself. This metadata augmentation is most likely possible, experiments have been conducted in other projects, but is out of scope for application in the MARVIC project. Therefore, this topic of metadata quality that is essential for evaluation of the potential for re-use is included in the awareness raising and capacity building mentioned in **Chapter 3.4.1.**

4. Conclusions and outlook

4.1 Uptake by project consortium

The uptake of this work by the consortium consists of the uptake of the metadata catalogue as a tool and the definition and application of the 4R principles that are applied to MRV. The metadata catalogue includes the results of the data inventories on benchmark sites and farm data as performed in the MARVIC project. Results of mitigation potential maps are foreseen to be included in the catalogue as well, as soon as they are published. MARVIC work on applying the MRV framework in the test cases, models and OPC's and designing smart soil sampling campaigns can explore the catalogue for suitable data layers that can inform their work. These are the usages for which it has been developed.

The discussions on the necessary filters for the catalogue to apply the 4R principle, and how the effective and efficient selection of data for MRV could be facilitated have increased the awareness on the specificities of MRV data requirements compared to more generic catalogues and repositories, the importance of the annotation of metadata and the possibilities and limits of a software application such as a metadata catalogue. As such, data and MRV data awareness has increased among consortium partners. The use of the 4R principles in data selection by consortium partners, WPs and tasks is likely present in one form or another, also as a result of this process. The catalogue is still improving and several issues are still being addressed as described in **Chapter 2.2**. We therefore expect an increase in uptake of the catalogue by the consortium after summer 2026.

4.2 Maintenance and improvement during project lifetime

As mentioned in **Chapter 2.2**, we have identified several underperforming functionality aspects and a needed review of the keywords in the metadata that can be improved before autumn 2026. Once these have been addressed as described in **Chapter 2.2**, we will maintain the functionality of the catalogue and the catalogue itself until 2 years after the end of the project. Between autumn 2026 and the end of the project the focus will be on enriching the metadata in the catalogue with new records, for example of MARVIC project results, but also with MRV4SOC project results and possibly other relevant sources identified in the SoilWise catalogue which is expected to be transferred to EUSO

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in spring 2027. At the end of the project the metadata content of the catalogue will be deposited in Zenodo as an update of the current Zenodo record (https://doi.org/10.5281/zenodo.20306053).

The collaboration within the Mission Soil Cluster on Knowledge and Data management and with the SoilWise project will be continued, as this has so far been beneficial to the development of the catalogue and the FAIR data guidances in webinars etc. Collaboration with CAFAMORE project is planned on metadata content and potentially on the catalogue (see **Chapter 4.3**).

4.3 After project outlook

The catalogue will be maintained until 2 years after the end of the project. During which time it is possible to add more metadata records, but this may not be actively pursued. At the end of the two years, an updated version of the metadata records will be deposited in Zenodo as an update of the current Zenodo record (https://doi.org/10.5281/zenodo.20306053) if the metadata content has changed since the last deposit.

The content of the metadata catalogue is harvested by SoilWise and the expectation is that this will not change after the project. If the catalogue is deprecated at some point in the future this will be communicated to SoilWise/EUSO and if needed appropriate measures will be taken (e.g. assign specific keywords/tags) to ensure that the metadata records remain available in the SoilWise/EUSO catalogue.

An option we aim to explore is the uptake and continuation of the MARVIC catalogue, including its specific MRV functionality, by the CAFAMORE project. Since WR, ILVO and other are partners in both projects, we expect this to be an easy transition, should CAFAMORE project decide to adopt the catalogue for its project and community purposes.

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MARVIC

MRV for carbon farming

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