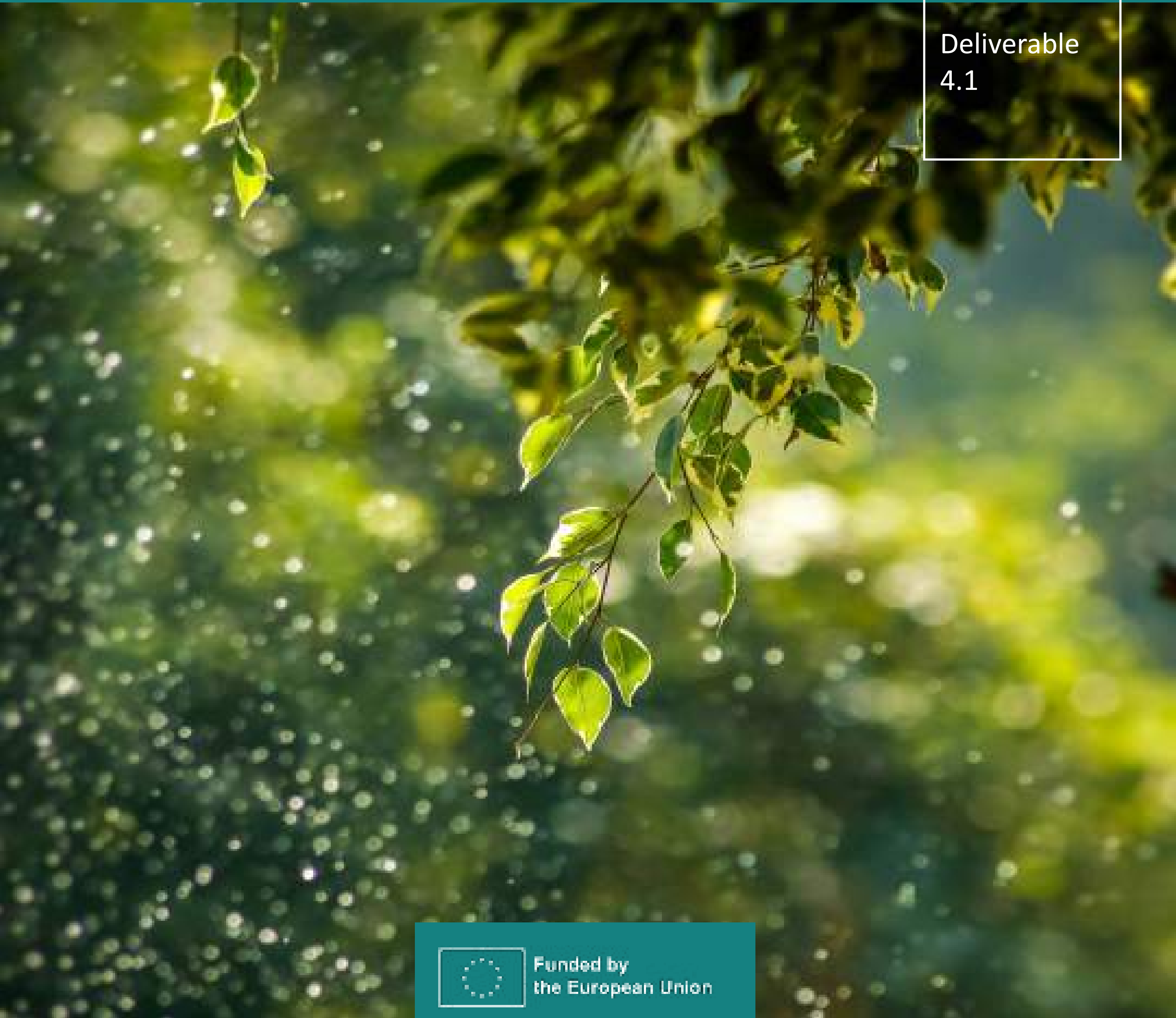
CARDIMED

CLIMATE ADAPTATION AND RESILIENCE DEMONSTRATED IN THE MEDITERRANEAN REGION

DEMOs' data collection strategies

Deliverable 4.1



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Contents

Executive summary.....16

1 Introduction.....17

1.1 Purpose of this document.....17

1.2 Intended Readership.....17

1.3 Document Structure.....18

2 Background.....18

2.1 Contribution of Nature-Based Solutions (NBS) in Climate Resilience.....18

2.1.1 NBS as part of the broader sustainable development and climate adaptation framework.....18

2.1.2 Connection between NBS and Climate Adaptation/Mitigation.....19

2.1.3 Rationale for Evaluating NBS's Contribution to Climate Resilience.....20

2.1.4 Existing Tools and Frameworks for Measuring NBS Impact.....20

2.2 The Role of Data Collection in NBS Impact Assessment.....22

3 NBS Impact Monitoring and Assessment.....24

3.1 Biodiversity Monitoring.....24

3.1.1 Indicators and Metrics.....24

3.1.2 Reflection on specific DEMOs.....25

3.2 Soil and Food Production.....27

3.2.1 Indicators and Metrics.....27

3.2.2 Reflection on specific DEMOs.....28

3.3 Forestry Mitigation.....29

3.3.1 Indicators and Metrics.....29

3.3.2 Reflection on specific DEMOs.....30

3.4 Stormwater Regulation and Water Quantity and Quality.....31

3.4.1 Indicators and Metrics.....31

3.4.2 Reflection on specific DEMOs.....31

3.5 Heat Mitigation.....35

3.5.1 Indicators and Metrics.....35

3.5.2 Reflection on specific DEMOs.....36

3.6 Energy.....37

3.6.1 Indicators and Metrics.....37

3.6.2 Reflection on specific DEMOs.....38

4 Data Collection Strategy.....41

4.1 Data Mapping Methodology 41
4.2 Data Ecosystem 43
4.2.1 Guidelines for Static Data and Geospatial Historical Data Integration 45
4.2.2 Guidelines for Data Integration of Laboratory Data.. 46
4.2.3 Guidelines for IoT Data Integration (In-Situ Sensors & Citizens-Science) 47
4.2.4 Guidelines for EO Data Integration.. 50
5 Unveiling the Data Landscape Playbook findings 51
5.1 Background..51
5.2 Discover DEMO 1 Data Assets 53
5.2.1 DEMO 1 Data Ecosystem Mapping 53
5.2.2 DEMO 1 Data Infrastructure 55
5.3 Discover DEMO2 Data Assets..57
5.3.1 DEMO 2 Data Ecosystem Mapping 57
5.3.2 DEMO 2 Data Infrastructure 59
5.4 Discover DEMO3 Data Assets..61
5.4.1 DEMO 3 Data Ecosystem Mapping 61
5.4.2 DEMO 3 Data Infrastructure 62
5.5 Discover DEMO4 Data Assets..64
5.5.1 DEMO 4 Data Ecosystem Mapping 64
5.5.2 DEMO 4 Data Infrastructure 66
5.6 Discover DEMO5 Data Assets..68
5.6.1 DEMO 5 Data Ecosystem Mapping 68
5.6.2 DEMO 5 Data Infrastructure 69
5.7 Discover DEMO6 Data Assets..72
5.7.1 DEMO 6 Data Ecosystem Mapping 72
5.7.2 DEMO 6 Data Infrastructure 73
5.8 Discover DEMO7 Data Assets..75
5.8.1 DEMO 7 Data Ecosystem Mapping 75
5.8.2 DEMO 7 Data Infrastructure 77
5.9 Discover DEMO8 Data Assets..79
5.9.1 DEMO 8 Data Ecosystem Mapping 79
5.9.2 DEMO 8 Data Infrastructure 80
5.10 Discover DEMO9 Data Assets 83
5.10.1 DEMO 9 Data Ecosystem Mapping.. 83
5.10.2 DEMO 9 Data Infrastructure.. 84
5.11 Data Ethics Canvas of CARDIMED's DEMOs 86

5.11.1 Data Openness ... 86
5.11.2 Open-accessed licences ... 88
6 Deployment of Data Collection Strategy Methodology ... 90
6.1 Data Integration Plan for DEMO1 ... 90
6.1.1 In-situ Data ... 90
6.1.2 Laboratory Data ... 92
6.1.3 Unstructured data ... 92
6.1.4 Data from existing services and data platforms ... 93
6.1.5 Earth Observation Data ... 95
6.2 Data Integration Plan for DEMO2 ... 95
6.2.1 In-situ Data ... 95
6.2.2 Laboratory Data ... 96
6.3 Data Integration Plan for DEMO3 ... 97
6.3.1 In-situ Data ... 97
6.3.2 Laboratory Data ... 98
6.4 Data Integration Plan for DEMO4 ... 100
6.4.1 In-situ Data ... 100
6.4.2 Laboratory Data ... 100
6.4.3 Unstructured Data ... 101
6.4.4 Data from existing Services and Data Platforms ... 101
6.4.5 Copernicus Earth Observation Data ... 103
6.5 Data Integration Plan for DEMO5 ... 103
6.5.1 In-situ Data ... 103
6.5.2 Unstructured Data ... 106
6.5.3 Structured Data from Custom Services ... 106
6.5.4 Data from existing Services and Data Platforms ... 107
6.5.5 Copernicus Earth Observation Data ... 109
6.6 Data Integration Plan for DEMO6 ... 109
6.6.1 In-situ Data ... 109
6.6.2 Data from existing Services and Data Platforms ... 109
6.7 Data Integration Plan for DEMO7 ... 110
6.7.1 In-situ Data ... 110
6.7.2 Structured Data from Custom Services ... 110
6.7.3 Data from existing Services and Data Platforms ... 112
6.7.4 Copernicus Earth Observation Data ... 114
6.8 Data Integration Plan for DEMO8 ... 115

6.8.1 In-situ Data ... 115
6.8.2 Laboratory Data ... 115
6.8.3 Unstructured Data ... 116
6.8.4 Structured Data from Custom Services ... 117
6.8.5 Data from existing Services and Data Platforms ... 117
6.8.6 Copernicus Earth Observation Data ... 118
6.9 Data Integration Plan for DEMO9 ... 119
6.9.1 In-situ Data ... 119
6.9.2 Laboratory Data ... 120
7 Conclusion ... 121
8 References ... 122
9 Annexe ... 126

List of Figures

Figure 1: Illustration of the beneficial contribution of D4.1 in the various upcoming deliverables and work packages. 17
Figure 2: How data streams can be generated for the NBS impact assessment. 23
Figure 3: Key benefits of employing the Data Landscape Playbook methodology in the Data Collection Process. 42
Figure 4: The four main pillars of the Data Landscape Playbook Framework as imposed by the ODI. 43
Figure 5: High-level presentation of the DEMO and sub-DEMO cases of the CARDIMED project. In the centre of the diagram, we present the whole project, which is divided into nine demo cases. In the third layer, the respective sub-demos are presented spanning different locations, where the NBS solutions will be applied.44
Figure 7: Indicative example of static data ingestion in the MW of CARDIMED. This integration imposed the necessity of a manual upload by a responsible actor (see additional examples in Chapter 6). 46
Figure 8: Examples of the different integrations that will be adopted for the historical datasets. 46
Figure 9: Integration of in-situ sensors and citizen science-driven data to the MW platform of CARDIMED following different data transmission and intercommunication protocols, or intermediate layers. 50
Figure 10: Integration of multisource EO-driven data streams to the MW, after the subsequent storage in the S3 bucket and the harmonisation according to the STAC specification. MW could have access to integrated EO datasets through the STAC API. 51
Figure 11: Data Ecosystem Mapping of DEMO 1, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers. ... 54
Figure 12: Data formats that have been chosen by DEMO 1 for storing the collected data. 55
Figure 13: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 1 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6). 56
Figure 14: Illustration of the temporal resolution that the released data assets will have in DEMO 1. 57
Figure 15: Illustration of the spatial resolution that the released data assets will have in DEMO 1. 57
Figure 16: Data Ecosystem Mapping of DEMO 2, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers. ... 58
Figure 17: Data formats that have been chosen by DEMO 2 for storing the collected data. 59
Figure 18: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 2 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6). 60
Figure 19: Illustration of the temporal resolution that the released data assets will have in DEMO 2. 60
Figure 20: Illustration of the spatial resolution that the released data assets will have in DEMO 2. 61
Figure 21: Data Ecosystem Mapping of DEMO 3, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers. ... 62
Figure 22: Data formats that have been chosen by DEMO 3 for storing the collected data. 63
Figure 23: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 3 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6). 63

Figure 24: Illustration of the tendency of DEMO 3 to maintain the data production through the pre-determined time intervals. 64
Figure 25: Illustration of the spatial resolution that the released data assets will have in DEMO 3. 64
Figure 26: Data Ecosystem Mapping of DEMO 4, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers. ... 65
Figure 27: Data formats that have been chosen by DEMO 4 for storing the collected data. 66
Figure 28: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 4 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6). 67
Figure 29: Illustration of the temporal resolution that the released data assets will have in DEMO 4. 67
Figure 30: Illustration of the spatial resolution that the released data assets will have in DEMO 4. 68
Figure 31: Data Ecosystem Mapping of DEMO 5, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers. ... 69
Figure 32: Data formats that have been chosen by DEMO 5 for storing the collected data. 70
Figure 33: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 5 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6). 71
Figure 34: Illustration of the temporal resolution that the released data assets will have in DEMO 5. 71
Figure 35: Illustration of the spatial resolution that the released data assets will have in DEMO 5. 72
Figure 36: Data Ecosystem Mapping of DEMO 6, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers. ... 73
Figure 37: Data formats that have been chosen by DEMO 6 for storing the collected data. 74
Figure 38: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 6 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6). 74
Figure 39: Illustration of the temporal resolution that the released data assets will have in DEMO 6. 75
Figure 40: Illustration of the spatial resolution that the released data assets will have in DEMO 6. 75
Figure 41: Data Ecosystem Mapping of DEMO 7, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers. ... 76
Figure 42: Data formats that have been chosen by DEMO 7 for storing the collected data. 77
Figure 43: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 7 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6). 78
Figure 44: Illustration of the temporal resolution that the released data assets will have in DEMO 7. 78
Figure 45: Illustration of the spatial resolution that the released data assets will have in DEMO 7. 79
Figure 46: Data Ecosystem Mapping of DEMO 8, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers. ... 80

Figure 47: Data formats that have been chosen by DEMO 8 for storing the collected data. 81
Figure 48: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 8 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6). 81
Figure 49: Illustration of the temporal resolution that the released data assets will have in DEMO 8. 82
Figure 50: Illustration of the spatial resolution that the released data assets will have in DEMO 8. 82
Figure 51: Data Ecosystem Mapping of DEMO 9, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers. ... 84
Figure 52: Data formats that have been chosen by DEMO 9 for storing the collected data. 85
Figure 53: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 9 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6). 85
Figure 54: Illustration of the temporal resolution that the released data assets will have in DEMO 9. 86
Figure 55: Illustration of the spatial resolution that the released data assets will have in DEMO 9. 86
Figure 56: Distribution of the data assets in the three categories of Data Spectrum (open, shared and closed). 87
Figure 57: Open-accessed licences that have been chosen by the data owners of every DEMO for the reported data assets. 88
Figure 58: In-situ data collection strategy in Lesbos Subdemo 90
Figure 59: In-situ data collection strategy in Mykonos Subdemo 91
Figure 60: In-situ data collection strategy in Sifnos Subdemo 92
Figure 61: Laboratory data collection strategy in Lesbos and Mykonos Subdemos. 92
Figure 62: Unstructured data collection strategy for Sifnos Subdemo 93
Figure 63: Data collection strategy from EUNIS platform for all subdemos 93
Figure 64: Data collection strategy from existing services and platforms that are related to Sifnos Subdemo94
Figure 65: EO data collection strategy for Sifnos sub-demo 95
Figure 66: In situ data collection strategy for Halcor Demo... 96
Figure 67: Laboratory data collection strategy for Halcor Demo.. 97
Figure 68: In situ data collection strategy for Alghero and Calich Lagoon... 98
Figure 69: Laboratory data collection strategy for Alghero and Calich Lagoon 100
Figure 70: In situ data collection strategy of Rain Garden in Catania 100
Figure 71: In situ data collection strategy of Green Wall of Feria... 100
Figure 72: Laboratory data collection strategy of Rain Garden in Catania (left) and Green Wall of Feria (right) 101
Figure 73: Visual Data collection from Rain Garden in Catania subdemo. 101
Figure 74: Data integration diagram of existing services and data platforms for both subdemos................ 102
Figure 75: EO Integration plan for Rain Garden in Catania and Green Wall of Feria.................................. 103
Figure 76: In situ common data integration plan for Saint Charles and Saint Jerome................................. 104
Figure 77: In-situ data integration plan for extra data sources of Saint Jérôme sub demo.......................... 105
Figure 78: In-situ data integration plan for extra data sources of Saint Charles sub-demo 105
Figure 79: Unstructured data integration plan for both Saint Charles and Saint Jerome sub-demos........... 106
Figure 80: Data integration of structured data that are not provided by existing services for both Saint Charles and Saint Jerome 106
Figure 81: Data integration of structured data that are not provided by existing services for Saint Jerome 107
Figure 82: Data integration diagram of existing services and data platforms for both subdemos................ 109

Figure 83: EO Data Integration diagram for sub-demos Saint Charles and Saint Jerome.............................. 109
Figure 84: In-situ data integration diagram from sensors supporting LoRaWAN protocol. 109
Figure 85: Architectural data integration diagram, where solar radiation and wind data are computed from rasterise data and collected in the Middleware. 110
Figure 86: In-situ data integration plan for Riverside Streams 110
Figure 87: Data integration of structured data that are not provided by existing services for Riverside Streams 111
Figure 88: Data integration of structured data that are not provided by existing services for Montados..... 112
Figure 89: Data integration plan for data from Climate Adapt Platform for Riverside Streams and Montados sub-demos 113
Figure 90: Data integration plan for Vegetation Cover from ESRI Portugal Platform for Riverside Streams . 114
Figure 91: Integration plan for Earth Observation data from Copernicus Land Cover for Riverside Streams and Montados 114
Figure 92: Integration plan for Earth Observation data from Copernicus Total Vegetation for Montados. .. 115
Figure 93: Data integration plan for in-situ sensors of DEMO 8 115
Figure 94: Data integration plan for laboratory data of DEMO 8.. 116
Figure 95: Unstructured data integration plan for DEMO 8.. 116
Figure 96: Structured data integration plan for DEMO 8 117
Figure 97: Data integration plan from existing services and data platforms for DEMO 8. 118
Figure 98: Integration plan for Earth Observation data from Copernicus Land Cover for DEMO 8 118
Figure 99: Data integration plan for in-situ sensors of DEMO 9 119
Figure 100: Data integration plan for laboratory data of DEMO 9 120

List of Tables

Table 1: Definition of the different processes of data collection and data generation, which are relevant to CARDIMED project. 24
Table 2: Analysis of the NBS indicators related to the biodiversity monitoring that are going to be used in the CARDIMED project, and in specific demo cases. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; **R**: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative. 25
Table 3: Analysis of the NBS indicators related to the soil health and food production that are going to be used in the CARDIMED project, and specific demo cases. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; **R**: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative. 28
Table 4: Analysis of the NBS indicators related to forest monitoring that are going to be used in the CARDIMED project, and specific demo cases. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; **R**: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative. 30
Table 5: Analysis of the NBS indicators related to stormwater regulation and water quantity and quality that are going to be used in the CARDIMED project, and specific demo cases. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; **R**: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative. 32
Table 6: Analysis of the NBS indicators related to heat mitigation that are going to be used in the CARDIMED project, and specific demo cases. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; **R**: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative. 36
Table 7: Analysis of the NBS indicators related to energy consumption that are going to be used in the CARDIMED project, and specific demo cases. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; **R**: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative. 38
Table 8: Number of the reported data streams per DEMO case, which are already collected by existing equipment or past collected campaigns (denoted as existing) or are planned to be collected (denoted as TBC) within the CARDIMED project. DEMOs highlighted in the last right column with Green, belong to the top 20% with the largest number of reported datasets. 52
Table 9: Definition of the variables that are going to be examined according to the guidelines of DLP, and the type of adopted analysis, denoting as **QN** the Quantitative and **QL** the Qualitative. 52
Table 10: Association of pixel sizes with mapping scales. 53
Table 11: Assessment of the FAIR compliance level in the reported local Open Data Portals/Catalogues. EU data providers are not imported in this analysis. 88
Table 12: Distribution of the open-accessed licenses for the reported data assets across the 9 DEMO cases. 89
Table 13: Presentation of the indicators that are tailored to evaluate the NBS impact assessment for the Biodiversity monitoring. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; R: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative. 126
Table 14: Presentation of the indicators that are tailored to evaluate the NBS impact assessment for the monitoring of soil health and food productivity. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; R: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative. 141
Table 15: Presentation of the indicators that are tailored to evaluate the NBS impact assessment for forestry monitoring. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; R: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative. 144

Table 16: Presentation of the indicators that are tailored to evaluate the NBS impact assessment for the stormwater regulation and water quality and quantity. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; R: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative. 145
Table 17: Presentation of the indicators that are tailored to evaluate the NBS impact assessment for heat mitigation. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; R: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative. 149
Table 18: Presentation of the indicators that are tailored to evaluate the NBS impact assessment for energy consumption. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; R: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative. 153

List of Abbreviations

Acronym	Full Name
AEMET	State Meteorological Agency
AGEA	Advanced Geological Environmental Assistance
AMU	Aix-Marseille University
API	Application Programming Interface
AQ	Air Quality
ASREA	Aquifer Surface Ratio with Excessive Arsenic
ASREN	Aquifer Surface Ratio with Excessive Nitrate
AWW	Agricultural Water Withdrawal
BOD5	Biological Oxygen Demand
C	Carbon
CA	Consortium Agreement
CAMS	Copernicus Atmosphere Monitoring Service
CAP	Common Agricultural Policy
CC	Creative Commons
CEREGE	European Center Research and Teaching in Geosciences De L'envi
Cfer	Chemical Fertility of The Soil
CIMAC	Intermunicipal Community of Central Alentejo
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
COD-BOC	Chemical And Biochemical Oxygen Demand
COG	Cloud Optimised Tiff
CR	Climate Resilience
CS	Citizen Science
CSVs	Comma-Separated Values
CtotalRW	Compliant Reclaimed Water
DDIWSS	Demand-Driven Industrial Water Symbiosis System
DEM	Digital Elevation Models
DLP	Data Landscape Playbook
DO	Dissolved Oxygen
DOGA	Doga Nature Association
DT	Digital Twin
DTM	Digital Terrain Model
EC	European Commission
EEA	European Environment Agency
EO	Earth Observation

ERT	Electrical Resistivity Tomography
ETL	Extract, Transform, and Load
EU	European Union
FAIR	Findable, Accessible, Interoperable, and Re-Useable
FAO	Food And Agriculture Organization
FTP	File Transfer Protocol
GAECs	Good Agricultural and Environmental Conditions
GFN	Global Footprint Network
GHG	Greenhouse Gases
GloREDa	Global Rainfall Erosivity Database
GPRS	General Packet Radio Service
GUI	Graphical User Interface
GWTeff	Effective Groundwater Treatment
HNMS	Hellenic National Meteorological Service
HR	High-Resolution
IAS	Invasive Alien Species
IDF	Intensity-Duration-Frequency Curve
IGN-F	Institut National De l'Information Géographique Et Forestière
IoT	Internet of Things
IUSTI	University Institute of Industrial Thermal Systems
IZMM	Izmir Metropolitan Municipality
IZSU	Izdoga, General Directorate of Izmir Water and Canalisation Authority
IZTECH	İzmir Institute of Technology
JRC	Joint Research Center
JSON	Javascript Object Notation
K	Potassium
LCZ	Local Climate Zone
LoRaWAN	Long Range Wide Area Network
LTE	Long-Term Evolution
LULC	Land Use/Land Cover
LWL	Linear Water Losses
M2M	Machine-To-Machine
MI	Nematode Maturity Index
MQTT	Message Queuing Telemetry Transport
MW	Middleware
N	Nitrogen
NBS	Nature-Based Solution
NDVI	Normalized Difference Vegetation Index

NetCDF	Network Common Data Form
NH4+	Ammonium
NO	Nitric Oxide
NO2	Nitrogen Dioxide
NO3	Nitrates
NOA	National Observatory of Athens
NRT	Near-Real-Time
Ntot	Total Nitrogen Concentration
O3	Ozone
ODbL	Open Data Commons Open Database License
ODI	Open Data Institute
OGC	Open Geospatial Consortium
OGL	Open Government License
OKF	Open Knowledge Foundation
OPC-UA	Open Platform Communications Unified Architecture
OPEKEPE	Greek Payment Authority of Common Agricultural Policy (CAP) Aid Schemes
ORD	Oxidation-Reduction Potential
P	Phosphorus
PACA	Provence-Alpes-Côte D'azur
PAR	Photosynthetically Active Radiation
PDF	Portable Document Format
PLC	Programmable Logic Controller
PM	Particulate Matter
PO4-P	Orthophosphate
PSTE	Region Of Central Greece
Ptot	Total Phosphorous Concentration
Pub/Sub	Publish/Subscribe
REHY	Reonhydor
RI	Rainfall Interception of NBS
RWnpU	Reclaimed Water in Non-Potable Uses
RWP	Reclaimed Water Production
SCADA	Supervisory Control and Data Acquisition
SDGs	Sustainable Development Goals
SIAS	Sicilian Agrometeorological Information Service
SITR	Regional Territorial Information System
SO2	Sulfur Dioxide
SO4	Sulphates
SOC	Soil Organic Carbon

SRI	Soil Resilience Index
STAC	Spatiotemporal Asset Catalog
SWTeff	Effective Stormwater Treatment
TBC	To Be Collected
TIFF	Tag Image File Format
TN	Total Nitrogen
TNn	Monthly Mean Value of Daily Minimum Temperature
TP	Total Phosphorus
TSS	Total Suspended Solids
TWC	Tap Water Consumption
TXx	Monthly Mean Value of Daily Maximum Temperature
UASB	Upflow Anaerobic Sludge Blanket
UN	United Nations
UNEP	United Nations Environment Programme
UNIBO	Alma Mater Studiorum - Universita Di Bologna
UNICT	University Of Catania
UNIVPM	Universita Politecnica Delle March
UV	Ultra-Violet
VHR	Very-High-Resolution
WEFE	Water-Energy-Food-Ecosystem
WFP	Water Footprint
WFS	Web Feature Services
WMS	Web Map Services
WMTS	Web Map Tile Services
WQC	Water Quality Compliance
WR	Water-Related Materials' Recovery
WSC	Water Storage Capacity
WWTeff	Effective Wastewater Treatment
WWTP	Wastewater Treatment Plant
XML	Extensible Markup Language

Executive summary

The main objective of this deliverable is to provide a comprehensive data collection strategy for the nine (9) demo cases of the CARDIMED project. This is accomplished with a series of activities which focused on the (a) the identification of the measurable NBS indicators, (b) the mapping of data-driven and integration demands per (sub)demo that are necessary to quantify the effectiveness of the NBSs impact, and (c) the spatiotemporal analysis required to fulfil the needs of the Water-Energy-Food-Ecosystem (WEFE) Nexus models (WP5).

Through a collaborative process of Tasks (T) 4.1 and 4.2, led by CREAF and ICCS respectively, and numerous iterations with demo partners, a plethora of indicators were identified addressing biodiversity, soil and food production, stormwater management and water quality and quantity, heat mitigation and energy, each time customised to the specificities of each demo case. Capitalising on the Data Playbook Landscape (DLP) methodology, the deliverable identified the existing and the upcoming data sources for each demo case, specified their characteristics and thus proposed a data integration plan, guiding this way the machine-to-machine intercommunication with the middleware (MW) platform of CARDIMED for anticipated reported data stream (i.e., earth observation, citizen science, in-situ, geospatial region-owned datasets, etc.).

Key elements of this methodology initially prioritised the demo-oriented NBS indicator list, enabling this way the identification of data streams that could fit the purpose and contribute to the quantification of the measurable impact of the deployed NBS. Key information was identified related to the responsible data owners, the data formats, accessibility interfaces, the spatiotemporal resolution, and their ethical profile, managed to complete the "data puzzle" for each demo case. The aforementioned characteristics tailored the design of a specific data integration strategy per (sub)demo and adopted the three following solutions, i.e., file server provided by the MW, Application Programming Interfaces (APIs) and Message Queuing Telemetry Transport (MQTT) brokers, which are in line with the supported infrastructure of the MW platform.

Facilitating this iterative desktop exercise, this deliverable fills the major gaps in the data collection process, and thus is expected to enhance the scalability and the applicability of NBSs throughout the project. This document provides a handbook, guiding the integration efforts required for each demo case from the MW platform (T4.4) which is expected to be described in D4.2 (Data orchestration module, M36). Finally, addressing the ethical aspects of the identified datasets provides a solid knowledge of the level of openness, and to what extent the demo cases have embraced the FAIR (Findable, Accessible, Interoperable, Reusable) guidelines as indicated in the submitted D1.2 (Data management plan – first version, M06).

1 Introduction

1.1 Purpose of this document

The purpose of this document is to provide the data collection strategy for each demo that will enable defining the different data streams that exist or will be produced within the project, so as to investigate the efficiency of the deployed NBS. The outcome of this document is a joined process of Tasks 4.1 and 4.2 but also capitalises on the outcomes of Task 2.2. (D2.2 - DEMOs value chains, monitoring & validation) in order to synthesise a strategy that will complement the designed monitoring plans and the upcoming pilot demonstrations (WP6). Additional requirements have been considered such as the spatiotemporal requirements imposed by the WEFE Nexus models (WP5) and the architectural design of the middleware platform of the CARDIMED project (Task 4.4), to assist in seamless data transmission and exploitation. Figure 1 illustrates the interconnections of this document throughout the various tasks and WPs of the project, reflecting this way its key importance.

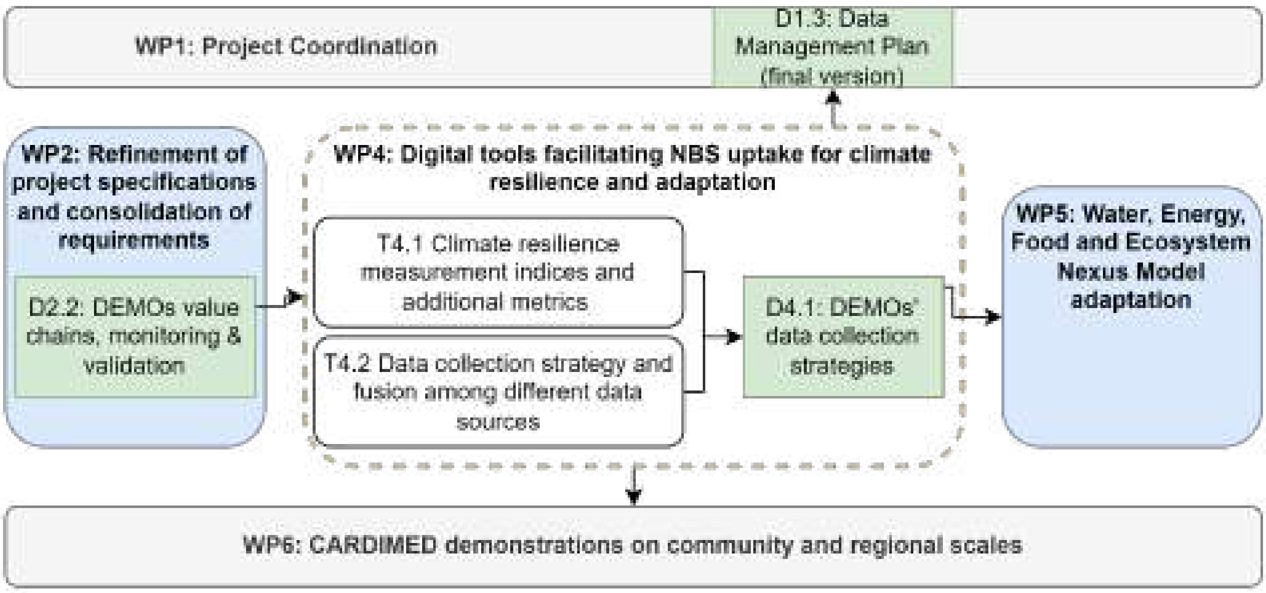


Figure 1: Illustration of the beneficial contribution of D4.1 in the various upcoming deliverables and work packages.

To formulate the data collection strategy, the well-documented methodology of the Open Data Institute (ODI) called Data Landscape Playbook (DLP) was used, which is comprised of four steps (called plays). For the first play, CREAF (Task 4.1 leader) provided at the beginning an extensive list of climate resilience indicators that could be used for the NBS impact assessment and therefore tailored to each demo case. The outcomes of this process oriented the next two steps of this process, where in collaboration with the demo leaders ICCS (Task 4.2 leader) defined the data collection strategy. Specific data integration pathways for each DEMO and data type is then presented, providing an extensive analysis of the various data providers, the datasets, the different aspects of data infrastructure and their ethical content. D4.1 also provides the different data integration flows required for each demo case considering the specificities of each data type and the technological capabilities of each DEMO.

1.2 Intended Readership

This deliverable is intended for public use, aiming to inform relevant stakeholders about the DLP methodology, the datasets produced and used in the context of the project, the data integration guidelines and the suitability of these data streams in the evaluation of the NBS. This document as well as the data catalogue with the integrated datasets for WP5's needs, which is foreseen to be delivered by M24 (MS6: "Integrated datasets for WP5 models") and should be considered as a handbook for NBS experts providing suggestions on how data can contribute to local climate resilience and how different data streams can be integrated into a common platform (Middleware platform of CARDIMED project).

1.3 Document Structure

This document is organised into 9 chapters, whose description is summarised through the following bullet points.

- **Chapter 1 - Introduction:** containing a short intro and overview of this document, and the intended readership of this document.
- **Chapter 2 – Background:** Outlines the beneficial contribution of the NBS to climate resilience and the critical importance of introducing accurate and curated data streams in order to measure their effectiveness.
- **Chapter 3 – NBS Impact Monitoring and Assessment:** Provides a comprehensive list of indicators for evaluating NBSs with respect to climate resilience. In a nutshell, this chapter aims to present the outcomes of T4.1.
- **Chapter 4 – Data Collection Strategy:** Provides an overview of the methodological steps of the DLP and directions on how to address each step of this analysis. Before delving into the analysis of the Data Ecosystems and the Ethical aspects of each demo, additional definitions and proposed integration methods are given for the different data types that we met during the data investigation process.
- **Chapter 5 – Unveil Data Ecosystem Maps and Data Ethics Canvas:** Demonstrates the results of the Data Ecosystem Mapping and Data Ethics Canvas analysis, and thus present for all DEMOs the data owners, the favourable data formats and access interfaces as well as the level of freedom regarding the data access.
- **Chapter 6 – Deployment of Data Collection Methodology:** Delve into each specific DEMO case and thus present a detailed integration plan with respect to the different data formats and different accessibility interfaces and communication protocols that will be adopted by DEMOs.
- **Chapter 7 – Conclusion and Future Plans:** Summarises the core elements of the document, including some final remarks on its contribution to the related tasks of the project.

2 Background

2.1 Contribution of Nature-Based Solutions (NBS) in Climate Resilience

2.1.1 NBS as part of the broader sustainable development and climate adaptation framework

NBSs are strategic tools towards achieving the 17 Sustainable Development Goals (SDGs) of the 2030 Agenda (United Nations, 2015), and their crucial importance under the threatening scenario of global change has been recognised in international treaties such as the Sendai Framework for Disaster Risk Reduction (United Nations, 2015) or the Strategic Plan for Biodiversity (Secretariat of the Convention on Biological Diversity, 2010). With obvious anthropocentric intention, the 2030 Agenda emphasises the need to protect, restore and manage sustainably natural resources for them to provide the vital environmental services that sustain the economy and social welfare. The agenda addresses all three dimensions of sustainability (environmental, social and economic) and stresses the importance of the involvement of multiple social actors. Addressing multiple sustainability objectives at the same time, beyond satisfying the main purpose of the action is a distinctive property of NBSs. Nevertheless, NBSs should not be considered effective until they prove to have delivered social, environmental and economic co-benefits and when trade-offs among different co-benefits are minimal (Gómez Martín et al., 2020).

The World Bank first introduced the NBS concept in 2008 (World Bank, 2008) to explain its investments in Biodiversity and Ecosystem protection. In particular, it was stated that *“Protecting forests and other natural* *ecosystems can provide social, economic, and environmental benefits, both directly through more sustainable management of biological resources and indirectly through the protection of ecosystem services*". Additionally, it was acknowledged that "Species and habitats are the building blocks on which human livelihoods depend, the foundation for productive forests, fisheries, and agricultural crops…" (World Bank, 2008). Concerning the aforementioned, World Bank declared that the "*enhanced protection and management of biological resources can mitigate these impacts and contribute to solutions as nations and communities strive to adapt to climate change*". This foundational document outlines an extensive set of actions and guidelines designed to deliver a plethora of benefits. These actions include the establishment of protected areas, afforesting and reforesting, conserving carbon stocks, restoring grasslands, peatlands and croplands, and protecting and adapting the management of terrestrial, marine and coastal areas to current threats.

The critical importance of NBSs has been further extended as the climate crisis evolves and thus officially presented in 2015 by the European Commission (EU, 2015), as "*actions that address environmental, social and economic challenges simultaneously by maximizing the benefits provided by nature*". However, this description was broad and without specific goals and actions. Coping with this limitation, in 2020, the IUCN produced NBS standards, which "*intend to be a simple yet robust hands-on tool that enables the translation of the NBS concept into targeted actions for implementation, reinforcing best practice, addressing and correcting shortfalls and enabling interventions to align with internationally accepted NBS principles*" (IUCN, 2020). International Union for Conservation of Nature (IUCN) standards can be summarised in the following eight criteria:

1. NBS effectively address societal challenges
2. The design of NBS is informed by scale
3. NBS result in a net gain to biodiversity and ecosystem integrity
4. NBS are economically viable
5. NBS is based on inclusive, transparent and empowering governance processes
6. NBS equitably balance trade-offs between the achievement of its primary goal(s) and the continued provision of multiple benefits
7. NBS are managed adaptively, based on evidence
8. NBS are sustainable and mainstreamed within an appropriate jurisdictional context

In addition to these criteria, the European Commission (EC) stated (EU, 2015) that NBS should be considered a pivotal asset as it "*helps build resilience … through locally adapted, resource-efficient and systemic interventions*". Nevertheless, NBS's contribution still remains elusive, encompassing a wide spectrum of strategies that can be adaptable to a variety of environmental situations. Some of these strategies and defining terms are compiled in the European Union (EU) Handbook for NBS practitioners (EC, 2021), and mainly address engineering interventions in urban, peri-urban and industrial environments (e.g. urban forestry, blue-green infrastructure, low-impact development, water-sensitive urban design, sustainable urban drainage systems, ecological engineering, best management practices, etc.).

Urban and peri-urban NBS are primarily executed at a low spatial scale, but others affect larger territories contributing to the landscape protection, restoration of damaged wild ecosystems, or sustainable management in forests, croplands and grasslands. Indicative examples of the applied large-scale solutions are area-based conservation, ecosystem-based management, ecosystem-based disaster risk reduction, socio-ecological production landscapes and sea spaces (Satoyama), as well as ecosystem-based adaptation and mitigation approaches (Dudley et al., 2020).

2.1.2 Connection between NBS and Climate Adaptation/Mitigation

Adaptation and Mitigation are considered the two core strategies for fighting climate change. The first one pursues increasing the environmental capacity to react and respond to climate stress, while the second seeks to reduce the release of carbon emissions into the atmosphere. At a global level, the premise of the NBS efficiency coupled with the sustainable management of occupied lands, will assist in the subsequent reduction of GHG emissions, enhance carbon sinks and eliminate the unfavourable impacts of climate change while reducing the vulnerability of social-ecological systems. Land-based NBS has shown a great potential for depleting the magnitude of emissions, enhancing carbon uptake as well as crop productivity, soil nutrient status, microclimate or biodiversity, which also supports adaptation to climate change (IPCC, 2019). Essential NBS for protecting and reinforcing environmental services can include both large-scale actions (rebuilding landscape connectivity, diversity, and functionality by restoration initiatives, or changes in forest and agricultural management) as well as engineered solutions at smaller scales.

Adaptation and mitigation are complementary strategies that promote climate resilience (Raymond et al., 2017), and thus it is essential to develop integrated NBSs that address both adaptation and mitigation and can be applied across different sectors and challenges (EC, 2015). NBS for adaption often addresses climate-related hazards and disaster risk reduction (inland flooding, coastal hazards, soil erosion, drought, wildfires, urban heat islands, etc.). However, low confidence in NBS's efficiency in protecting humans and infrastructures against natural disasters and the low response of the degraded ecosystems are often cited as hindrances to the wider adoption of NBS.

In favour of mistruth, NBS are not always efficient enough against risks of very high intensity, whereas, in the same sense, NBS based on natural materials (generally vegetal elements) require significant time to showcase their full potential. In the opposite sense, NBS for adaptation are usually more cost-effective than hard grey infrastructures addressing climate hazards and are more adaptable to further changes in risk (Jones et al., 2012). When working for adaptation and mitigation, NBS can be used as a part of hybrid strategies to reinforce the effectiveness of engineered solutions and to reduce their cost. Lately, essential efforts have been made to exploit synergies between conventional grey solutions and NBS (Kapos et al. 2019; Sowińska- Świerkosza & García, 2022).

2.1.3 Rationale for Evaluating NBS's Contribution to Climate Resilience

To increase the credibility of NBS, it is necessary to overcome two important barriers, the NBS context-specificity (in terms of the biophysical and social conditions of the system) and sensitiveness to climate, which implies that both environment response and NBS effectiveness can change across space and time (Kapos *et al.* 2019). Given these characteristics, the inability to generalize the effects of interventions based on NBS may represent the most significant barrier to their widespread adoption. In the absence of a reliable assessment of impact across varying scenarios, any intentions to replicate and upscale these interventions seem hard to achieve, as in many cases essential time and effort are given to tailor an NBS strategy (Frantzeskaki, 2019).

To address this challenge, comprehensive data about NBS performance and impact from monitoring plans, field studies, and dissemination of monitoring and impact assessment are required to enable the inclusion of NBS strategies in urban and regional planning and design (EC, 2021). Nevertheless, this exercise is characterised as troublesome (Vollmer et al. (2024), due to the difficulty in choosing and measuring relevant indicators and the impact on immaterial services (mainly regulating and social and cultural services) as it is often assessed through monetary methods that suffer from different biases and weaknesses. Furthermore, physical and chemical indicators are often expensive, labour-intensive and require highly experienced personnel. Thus, the above-mentioned context-specificity of NBS makes it impractical to universalise baselines or optimal values for a given indicator. As a result, the significant importance of NBS is usually overlooked, especially when assessments are costly, and the knowledge is very limited. This highlights the need to develop sound and trustable frameworks for assessing NBS impacts on the whole social-environmental system.

2.1.4 Existing Tools and Frameworks for Measuring NBS Impact

There is abundant literature on impact assessment of specific NBS on specific environmental contexts, but almost all existing reports are sectoral and do not contemplate interaction between impacts (Dimitriu et al., 2020). The majority of the existing references reflect outcomes on the establishment of NBS in urban environments, from EU-funded projects (Dumitriu et al. 2020; Kabisch et al., 2016; Raymond et al., 2017b). Hydrometeorological risks (Kumar et al., 2021), Disaster risk reduction (Veerkamp et al., 2021) and Biodiversity management in protected areas (Dalton et al., 2024) are also well documented. When it comes to the forested and natural environments, the NBS concept often overlaps with Ecosystem Restoration for which the Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP) produced a monitoring framework (FAO and UNEP, 2022). Of all the aforementioned initiatives, two are worthy to be noted.

In 2017, under Horizon 2020, Raymond et al. (2017) coordinated an Eklipse Integrated Evaluation Framework for assessing the performance of NBS in dealing with the following 10 challenges related to climate resilience in urban environments. These are climate mitigation and adaptation, water management, coastal resilience, green space management (including enhancing/ conserving urban biodiversity), air/ambient quality, urban regeneration, participatory planning and governance, social justice and social cohesion, public health and well-being, and potential for new economic opportunities and green jobs. This framework recognised the difficulties of providing a single answer for the impact assessment of NBSs as they vary across social and ecological contexts, and temporal and geographical scales. Drawbacks and advantages were also reported, highlighting the implications of synergies and antagonism between benefits. However, it failed to establish assessment methods and indicators for the latter.

From the Eklipse initiative, the NBS Impact Evaluation Taskforce, integrated by 17 individual EU-funded projects, the European Environment Agency (EEA), the Joint Research Centre (JRC) and a vast number of European researchers generated an integrated NBS assessment tailored to urban environments at different scales (EC, 2021). The document is a compendium of measurement methods intended "*to support the adoption of common indicators and methods for assessing the performance and impact*" of a variety of NBSs, (Wendling *et al.* 2021). The first (of two) volumes of the work builds on approaches and tools generated in EU-funded projects on NBS in urban environments and addresses 12 challenges: Climate resilience, Water management, Natural and climate hazards, Green space management, Biodiversity enhancement, Air quality, Place regeneration, Knowledge and social capacity building for sustainable urban transformation, Participatory planning and governance, Social justice and social cohesion, Health and wellbeing and New economic opportunities and green jobs. The second volume of the work takes the form of a Handbook for practitioners and includes a comprehensive list of indicators applicable for assessment.

The authors stated that "*In order to compare different types of NBS, implemented in different environments and at varying scales we need to measure the same variables, using the same methods and report these outcomes using the same units of measure*" (Wendling *et al.* 2021). This statement is most probably the origin of some failures of the report. As stated, the relevance of many indicators is highly dependent on bioclimatic properties and spatial scale. This is especially relevant for indicators relative to the biological and social compartments of the environment, by contrast with physical and chemical processes (as for pollutants, climate islands, etc.). This very important work also fails to address the interactions and trade-offs between indicators or the intrinsic evolution of natural constituents of the NBS over time.

To address deficiencies in more conservative frameworks, the **WEFE (Water-Energy-food-Ecosystem) nexus assessment framework is now meant to evaluate** the impacts of any type of action on interlinkages among biodiversity, water, food, health, and climate change (referred to as "the nexus"). The main virtue of this approach is to avoid siloed approaches that can perpetuate practices that enhance one specific environmental service to the detriment of others (Newell et al., 2019). A complete holistic approach must also recognise that food, energy, water, and ecosystems are inextricably entangled (Carmona-Moreno et al., 2021) and must integrate management and governance across the multiple sectors of the nature-society system as one single whole. The WEFE-Nexus concept and its practical deployment have significantly evolved since the Bonn 2011 Nexus Conference and, in its current form, it is a promising tool to advance the completion of the Sustainable Development Goals acknowledged by the 2030 Agenda (Carmona-Moreno et al., 2018). Indeed, any solution affecting one of the components of the system is bound to produce collateral impacts and potential synergies and antagonisms whose dimension and sign must be evaluated for a fair nexus balance.

At an operational level, a great number of variables are required for integrated evaluation, and their frequent unavailability is one of the major difficulties to overcome (Fleischmann et al., 2024). In practice, most evaluations disregard important components of the “Environment” term. In this sense, only recently some works have brought attention to the consequences of NBS on climate through the evaluation of carbon (C) fluxes and even then, atmosphere-soil fluxes are ignored (Segura-Barrero et al., 2024). When soil health and biodiversity are included within expected outcomes, it is mostly in a qualitative manner (Vanino et al., 2024).

Reducing WEFE nexus to WEF evaluation, evaluating only one or two of the Nexus pillars and disregarding the influence of external factors impacting the water, energy, and water sectors (e.g. land use, demography, environmental protection, etc.) limits its utility for NBS assessment (IRENA, 2015; Miralles-Wilhelm, 2016) and further effort must be invested to generate holistic and flexible models of system's functioning within its context.

2.2 The Role of Data Collection in NBS Impact Assessment

The successfully invest our resources in a sustainable urbanised environment and contribute to the United Nations' (UN) sustainable goals, there is a radical need to embrace solutions that could address this complex system as the urban landscape is and therefore invest towards the resilient planning and practices that will ensure the liveable ecosystem. During the latest years, NBSs have been at the forefront of the investigated practices and are strongly supported by the EC, as they can create a knock-on effect and transform multiple challenges (e.g., social dimensions, economic development, positive environmental impacts, etc.). Nevertheless, NBSs cannot be considered a panacea, as they might offer completely opposite results if proper strategic planning and evaluation do not come first. Thus, it is of paramount importance to introduce a robust assessment framework on the applied NBS and verify it not only as an isolated system but also as an interconnected and transdisciplinary system, which affects more than one aspect. This framework should provide unquestionable evidence alongside the demonstration phases of the NBS and retrofitting decision-makers with accurate outcomes of all the evaluation phases, offering this way adaptive and agile management and planning. Trustworthy insights should establish a baseline indicating the natural process of an ecosystem without any intervention, in order to monitor and evaluate the impacts generated by a specific NBS treatment (Chrysoulakis et al, 2021). Sowińska-Świerkosz and García (2021) have stated that an *“effective intervention should be evidence-based, integrate traditional knowledge and be supported by the best available data, research and practice”*.

Therefore, the selection of specific evaluation indicators of NBSs must be data-abided in order to introduce a methodological framework of NBSs that could be proven efficient, effective, reliable and not resource-consuming. The capability of an indicator to be applied and evaluated is expressed by a single term, measurability. “Measurability refers to the ability of data or easy data collection and easy indicator analysis and update, as that the effectiveness analysis does not consume most of the resources meant for solution management” (Kabisch et al., 2016; Lindenmayer et al., 2015). The digitalisation evolution is characterized as a lighthouse towards the improvement of the measurability of the chosen indicators. Until recently, the evaluation of the NBS was implemented by in some cases direct measurements, however in the absence of these observations indirect estimations or results from previous investigations and literature reviews were applied to fill this data gap. The latest could be considered as an approximation of the actual conditions that are taking place in a specific location and a starting point for further analysis but are characterised by uncertainty. The lack of relevant and up-to-date data is a hindrance that has been reported by several researchers (Bauduceau et al., 2015; Nesshöver; 2017; Sowińska-Świerkosz, 2021). This drawback generates critical implications when the assessment is applied based on the following two factors: (a) measurements of environmental variables, in which the total evaluation indicates the ex-ante and ex-post assessment in order to perform a comparison, and (b) the synergies and trade-offs between different treatments, as they are very complex and hard to be captured (Raymond et al., 2017).

Hence, the need to introduce novel data collection tools and generation methods is of major importance, as they are capable of revolutionising the evaluation framework and the systematic mapping of their positive impact on both society and the environment, and therefore the trade-offs between different applied treatments. To establish data-driven monitoring plans, it is required to assess the data requirements concerning their cost-efficiency, applicability, and efficacy for the designed evaluation framework. The generated data should be applicable both to the NBS impact assessment and curated in order to perform comparisons with former or upcoming campaigns (Wendling, 2021).

As it is illustrated in Figure 2 (Wendling, 2021) data requirements can be substantially differentiated based on the type, their acquisition payload and the technique of data collection. Considering the scale under which the impact assessment is performed and the specificity of the applied NBS various data streams can be produced, either from a single acquisition strategy or assimilated data production. The most distinct data division is related to the absence or not of the geospatial information of where a data source was taken. Notwithstanding, there are several cases where the aforementioned two are integrated and thus upscale the useability of the non-spatial data source. Another categorisation is associated with the way of use. In other words, to perform the impact assessment on a NBS, there is a need to perform baseline analysis and a causal-and-effect investigation of the NBS interventions. Thus, the data that is explored in the first category are denoted as “reference” and try to establish a quantitative condition before the intervention, whereas control data are declared the ones utilised for the estimation of the counterfactual (Wendling, 2021).

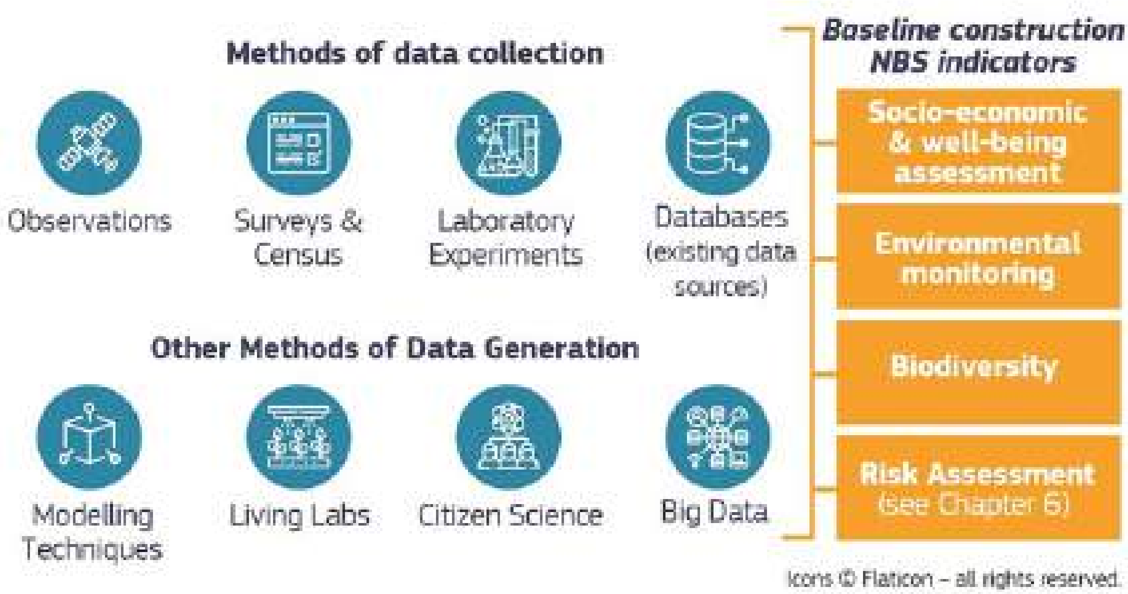


Figure 2: How data streams can be generated for the NBS impact assessment.

Furthermore, two subsequent data categories which are going to be also extensively examined in this deliverable are the acquisition regime (temporal resolution) and the spatial scale (spatial resolution).

The INSPIRE Directive (EC, 2007) distinguished the acquisition regime with the following four categories:

- **Continuous** are denoted data, generated continuously.
- **Demand-driven** are the ones created based on a specific need.
- **Once-off** data is a source of information, which is generated only a single time, without any expectations for updates.
- **Periodic** data collection reflects the condition of when a dataset is produced at regular intervals.

Nevertheless, at this stage of the project, we avoided using the suggested categorisation and thus maintain the actual temporal characteristics, preserving this way the maximum level of clarity. The same rationale was adopted for the spatial resolution as well, avoiding adopting the following classification scheme. Further details can be found in Chapter 5.1.

- Landscape or regional scale
- City scale
- Neighbourhood scale
- Street or pedestrian scale
- NBS footprint scale

When it comes to the processes of data generation and collection (Figure 2), data can be collected by several processes to properly monitor and assess the efficiency of the deployed NBS. In the CARDIMED project, we adopted the following data collection methods were established, (Table 1).

Table 1: Definition of the different processes of data collection and data generation, which are relevant to CARDIMED project.

Data generation processes	Definitions
Data collection methods	
Observations	Direct measurements are collected by either automated or manual methods in order to monitor the performance of an NBS without any human interference during the observation. The collection of these kinds of data streams is usually implemented by two sensing monitors, the Earth Observation data acquisition missions and the Internet of Things (IoT) networks. The first has been designed to capture different parts of the earth in frequent time intervals. Whereas airborne and drone-based campaigns are usually conducted on demand.
Surveys and Census	Collects the subjective perceptions of participants over the performance of an NBS, assessing the environmental and social impact.
Laboratory experiments	Manipulate raw variables in order to investigate the phenomenon under study.
Data generation methods	
Numerical modelling	Data-driven or mechanistic models are keen to unveil additional outcomes based on the directly collected datasets and better represent real-world systems.
Big Data	Generation of datasets, which are expressed by the 5V's characteristics (volume, value, variety, velocity, and veracity) and cannot be handled by conventional data processing software.
Citizen Science	Refers to public participation usually with low-cost sensing monitors in order to actively engage in the data generation process. This is further expressed by three different forms, the contributory, the collaborative and the co-created.

3 NBS Impact Monitoring and Assessment

3.1 Biodiversity Monitoring

3.1.1 Indicators and Metrics

The unprecedented decline in global biodiversity has pushed the global community to set numerous international agreements and goals to slow this decline, and there is a need to use indicators to measure changes in biodiversity and its drivers when applying NBS. Biodiversity indicators are one of the most widely used indicators for assessing and monitoring NBS because of their direct link to the species and ecosystems conservation, health and services, and their impact on human well-being in both natural and urban habitats.

Biodiversity indicators are essential for planning, implementing and evaluating the effectiveness of NBS. They can help stakeholders to track progress and identify management strategies that need to be adjusted to avoid negative outcomes and provide information on ecosystem health, stability and functioning, provisioning and resources, climate regulation, resilience to environmental change, etc.

There is a myriad of biodiversity indicators, but the most commonly used are at the species level. Indicative examples are species richness, species diversity (including functional and genetic diversity), cover, biomass, productivity, reproduction, survival, mortality, phenology, endangered or protected species, invasive species; or at the habitat or landscape level: species interactions, connectivity, fragmentation, habitat area, habitat quality, restored habitat area, protected areas or derived satellite data.

The use of biodiversity indicators to monitor NBS poses several challenges. The first is to consider all aspects related to biodiversity and to capture the important aspects of the NBS system. Biodiversity indicators cover a wide range of aspects at different spatial and temporal scales, from species to ecosystems or from hours to decades, and selecting the right indicator is sometimes challenging. In addition, the lack of data availability or the difficulty in obtaining some data (due to economic, human, temporal or technological issues) hampers the applicability of these indicators. Some indicators are relatively easy to obtain (e.g. those derived directly from satellite imagery), but others are time and cost-consuming or require specialised machinery or trained specialists. The overall synthesis of the indicators related to biodiversity monitoring is presented in the Annex (Table 13). Nevertheless, the following chapter attempts to shed light on the applicability of several indicators in the specific demos, which will be evaluated with specific data streams reported in the specific sections of Chapter 5.

3.1.2 Reflection on specific DEMOs

All the indicators in 3.1.1 have been reviewed together with DEMO leaders. Through a series of workshops, the domain experts from CREAF, MINUARTIA, and other experts, together with local partners, identified and selected which of those indicators will be monitored, based on local specificities and needs. Those identified indicators are presented in Table 2. The identified indicators are not present in the previous table to avoid repetition. A detailed monitoring plan, including the relevance of indicators, equipment needed, sampling plan and frequency is described in detail for each DEMO in Deliverable 2.2.

*Table 2: Analysis of the NBS indicators related to the biodiversity monitoring that are going to be used in the CARDIMED project, and in specific demo cases. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; **R**: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative.*

Indicator	Unit	Used in Demo	Description	Climate strategy
Area covered by invasive species	ha	D7	Area covered by alien species	R
The area of habitat created	ha	D1	Area of the focal habitat that is created in a project	M
Area of habitats restored	ha	D7, D8	When NBS delivery is associated with the restoration of target habitats (e.g., Article 17 habitats, national priority habitats, or local priority habitats), quantification of the extent of restored habitats can function as an indicator of success. It is calculated as the extent of habitat as a proportion of the total area, or total area of a specific habitat type (e.g., proportion of amenity grassland restored to wildflower meadow)	M

Area of habitats under the EU Habitats Directive	ha	D7	Area covered with habitats included in the EU Habitats Directive	R
Focus or key habitat(s) area	ha	D8	Area of the focal habitat or habitats of interest (e.g. reed beds, Typha beds, seagrass, etc.)	R
Linear meters of linear landscape elements affected by invasive species	m	D7	Linear meters of linear landscape elements (river/roads/paths/coastline...) affected by invasive species	R
The number of focal habitat specialist species (e.g. saltmarshes, wetlands, riverine or riparian, dune, halophyte, macrophyte, seagrass, etc.)	Num ber	D8	The number of plant species that are specialists to a focal habitat of interest, that is, only or mainly grow in that habitat of interest like saltmarshes, wetlands, riverine or riparian, dune, halophyte, macrophyte, seagrass, etc.	R
Number of parasitized plants/trees	Ind./ m2 or Ind./ ha	D6	Number of parasitized plants in a given area	I
Number of planted trees and shrubs	Num ber	D6, D7	Number of trees and shrubs planted in a project	M
Survival rate	%	D7	The survival rate within a population, e.g., of trees after planting	I
Tree density	Ind./ ha	D6	Number of trees per hectare	I
Percentage of Affected Trees by Degree of Infestation at Tree Level	%	D6	This indicator measures the proportion of trees in a specific forest area that are affected by mistletoe, categorized by the severity of the infestation. It is expressed as a percentage.	I
Species richness within a target fauna group or taxa	Num ber	D5, D6, D7, D8, D9	Total number of species within a target group or taxon,	A
Habitat surface for target fauna indicator species	m^2	D4	It allows monitoring the habitat area to, at least, one fauna-specific species (i.e., bird, amphibian, insect) which is taken as an indicator of the ecological quality of the study of cases. (According to a standardized method to be described)	A & R
Marsh Frog Abundance	and/ m^2	D1	This refers to the population size of marsh frogs in the NBS-affected area, often used as an indicator of wetland ecosystem health. This indicator is measured by the number of individuals per unit area (e.g., frogs per square meter or per hectare) during a specific time period	R
Area Of Mediterranean	ha	D1	This measures the surface area of temporary wetlands or ponds that have been established in	M

Temporary Ponds Created			ecosystems as part of conservation or restoration efforts from the NBS	
New Functional Fauna Habitat	ha	D5	This refers to newly created or restored habitats that are specifically designed or managed to support wildlife populations, enhancing ecological functionality.	M
New Protected Habitat Area	ha	D7, D8, D9	This refers to areas that have been newly designated or legally protected to conserve biodiversity and ecosystem services	M
New Refuges for fauna installed	numb er	D8	This refers to the creation or installation of artificial or enhanced habitats designed to provide shelter, breeding, or feeding areas for wildlife. This indicator is usually measured by the number of refuges created or their total surface area, and it helps assess efforts to support wildlife, particularly in areas where natural habitats have been degraded or lost	M

3.2 Soil and Food Production

3.2.1 Indicators and Metrics

Despite overwhelming evidence of the importance of maintaining and restoring soil health, it is seldom considered in NBS monitoring plans. In our in-depth review of indicators proposed for NBS monitoring in EC-funded projects and reference reports on NBS, only 49 indicators (of 570) addressed soil.

The growing interest in soil, a terrestrial compartment that has been historically neglected, is linked to the recognition of the crucial environmental services it provides to human societies. In the face of the current global crisis, soil appears as a strategic tool for mitigating climate change, reducing risks associated with it, and developing adaptation strategies. It is important to stress that soil does not have an autonomous functioning but is part of a complex organism integrated by plants, mineral substrates and organisms inhabiting the soil matrix and the rhizosphere. All these elements working together provide our food and the fibres we use and regulate the hydrological and atmospheric cycles, including the carbon cycle.

The vast majority of NBS use the soil-plant organism as a tool or alter it in one or another form. Therefore, the environmental services provided by soil should be included in NBS monitoring plans from one or both of the following perspectives: either soil restoration is a KPI of the impact of the action or conserving and improving soil health makes part of the environmental co-benefits required for an NBS to be admitted as such.

Soil organic C stocks can be dramatically affected by NBS when the programmed actions include changes in land use. For example, in mineral soils reforesting croplands with native vegetation or planting trees on grasslands can increase SOC stocks by up to 25-40% in the upper horizons. Changes in soil management can also significantly influence the CO_2 sequestration/emission balance.

Increasing or preserving SOC stocks triggers a number of collateral environmental benefits such as increased nutrient storage and water retention capacity, greater resistance to erosion, improved fertility for food production, etc., although unfortunately trade-offs between these services often hamper the assessment of NBS impacts.

Soil sealing and compaction drastically reduce porosity and permeability, leading to the deterioration of soil structure, as well as the disruption of aggregate distribution and stability. As a result, these processes increase the risk of erosion and promote soil loss. Maintaining soil structure plays a crucial role in enhancing the resilience of ecosystems to extreme climate events, such as floods, droughts, and heat waves.

An important consequence of disturbing soil is affecting soil biodiversity and, in fact, most services attributed to plants are totally or partially produced by soil organisms. Among these services, food production is vital for humans. For a given climate, food production depends on a complex combination of soil properties that integrate the “soil fertility” concept. Soil is fertile for a given plant product when it meets plant requirements in physical structure, chemical properties, and biological composition and activity. Therefore, as with most soil indicators or indexes, fertility is strictly context-dependent and rejects assessment through standardized thresholds of isolated properties. Measuring food production in weight per unit area is a synthetic approach to soil fertility under appropriate water availability and climate. The overall synthesis of the indicators related to the monitoring of soil health and food productivity is presented in Chapter 9 (Table 14). Nevertheless, the following chapter attempts to shed light on the applicability of several indicators in the specific demos, which will be evaluated with specific data streams reported in the specific sections of Chapter 5.

3.2.2 Reflection on specific DEMOs

All the indicators in 3.2.1 have been reviewed together with DEMO leaders. Through a series of workshops the domain experts from CREAF, together with local partners, identified and selected which of those indicators would be monitored, based on local specificities and needs. Those identified indicators are collected in the table below. The identified indicators are not present in the previous table to avoid repetition. A detailed monitoring plan, including the relevance of indicators, equipment needed, sampling plan and frequency is described in detail for each DEMO in Deliverable 2.2.

Table 3: Analysis of the NBS indicators related to the soil health and food production that are going to be used in the CARDIMED project, and specific demo cases. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, ***ER****: Enhance Resilience;* ***R****: Resilience;* ***M****: Mitigation;* ***A****: Adaptation;* ***A & R:*** *Adaptation on Resilience;* ***I****: Indicative.*

Indicator	Unit	Used in Demo	Description	Climate strategy
Bulk density	$g.cm^{-3}$	D1, D3, D5, D6, D7, D8, D9	Informs on compaction ISO 11272:2017 for determination of dry bulk density	R
Chemical fertility of the soil – Cfer -	$mg.kg^{-1}$	D1, D3, D5, D6, D7, D8, D9	Relates to the mineral nutrition of plants via the concepts of bioavailability of elements, deficiencies, toxicities and equilibria	A & R
Microbial diversity by DNA metabarcoding	Unitless	D3	Informs about the taxonomic diversity of microbial groups	R
Nematode Maturity Index (MI)	Scored between 2 and 5	D1, D6, D7, D8	A maturity index taking into account soil nematodes except for plant feeders. Provides information on environmental perturbation and contamination and increases with environmental stability	R
Penetration resistance	MPa	D3	Informs about soil compaction	A

Soil respiration	mmol m^{-2} h^{-1}	D1, D5, D6	Represents respiration rates of soil microbes, fauna and roots. When roots are eliminated, together with soil microbial biomass inform on soil stress	M
Soil sealing	km^2	D5, D6	The land area covered by impermeable materials	M
Total SOC analysed	g C kg of soil $^{-1}$	D1, D3, D5, D6, D7, D8	Changes in SOC inform about C sequestration in soil	M
Water holding Capacity (measured)	% water/volume of saturated soil	D1, D3, D5, D6, D7, D8, D9	The ability of soil to store water against the force of gravity	A & R
Soil toxicity tests (ISO) on *Folsomia*	% survival	D8	A non- substance specific test of the presence of pollutants in soil	R

3.3 Forestry Mitigation

3.3.1 Indicators and Metrics

Forests perform crucial functions such as carbon (C) sequestration and consequently play a key role in mitigating climate change. However, forests also provide other equally important functions, including water regulation, flood prevention, and soil erosion control. In fact, forests are among the most significant providers of ecosystem services. Yet, the increasing pressures they face—whether due to land-use changes or climate change—underscore the importance of identifying and quantifying the services these ecosystems provide and determining which are most vulnerable in the context of global change.

In the context of the carbon (C) cycle, forests and their soils hold the majority of the Earth's terrestrial carbon stocks and regulate the primary terrestrial fluxes of C between the atmosphere and the biosphere. Forests cover more than 4.1×10^9 hectares of the Earth's land area and store approximately 1,146 Pg C (1 Pg = 10^9 Mg = 10^{15} g) in vegetation and soils. Of this carbon stock, about 37% is found in tropical forests, 14% in temperate forests, and 49% in boreal forests. Globally, forests act as net C sinks, representing the dominant component of the terrestrial C sink and accounting for the removal of 25–30% of all anthropogenic C emissions.

Natural disturbances (e.g., wildfires, wind, storms) and human-induced disturbances through management practices (e.g., clearing, thinning, reforestation) are also important determinants of stand C stock and carbon sequestration due to changes in stand structure and diversity. Management is a man-controlled disturbance that turns forests into short-term sources of CO_2 but that allows high stand productivity in the mid-term by reducing competition for resources.

Mediterranean forests were intensively managed for timber production throughout the last century. However, in recent decades, forest expansion following agricultural abandonment and a decline in forest management have been identified as key factors contributing to the increase in carbon (C) stock in many forested areas. This forest densification can be particularly detrimental in water-limited forests, such as those in the Mediterranean region, as it reduces water availability per tree, potentially predisposing forests to drought-induced growth declines and mortality events. The abandonment of management intensifies competition among trees, typically leading to reduced growth, higher mortality rates, and decreased forest health. In Mediterranean forest ecosystems, where climate change is projected to be particularly severe due to rapid warming and reduced precipitation, the combined effects of land-use changes and climate change on forest growth and mortality could be especially damaging. To mitigate the impacts of climate change and ensure that Mediterranean forests continue to provide their essential functions, it is crucial to maintain their health, which can largely be achieved through appropriate forest management practices that regulate competition for resources among trees.

For all these reasons, and as reflected in the proposed indicators, it is essential to have a detailed understanding of forest dynamics resulting from silvicultural practices. This involves quantifying, on one hand, the rates of biomass or carbon loss due to mortality or forest management, and on the other hand, the increase in stocks due to the growth of surviving trees and the incorporation of new trees (regeneration). By balancing gains and losses, it is possible to determine the carbon stock at any given time. A positive balance indicates net CO_2 sequestration, while a negative balance signifies net CO_2 emissions. The overall list of the indicators related to the monitoring of forestry mitigation is presented in Chapter 9 (Table 15). The following chapter presents the list of indicators that are going to be used in this project and for specific demos.

3.3.2 Reflection on specific DEMOs

All the indicators in 3.3.1 have been reviewed together with DEMO leaders. Through a series of workshops the domain experts from CREAF, together with local partners, identified and selected which of those indicators would be monitored, based on local specificities and needs. Those identified indicators are collected in the table below. The identified indicators are not present in the previous table to avoid repetition. A detailed monitoring plan, including the relevance of indicators, equipment needed, sampling plan and frequency is described in detail for each DEMO in Deliverable 2.2.

*Table 4: Analysis of the NBS indicators related to forest monitoring that are going to be used in the CARDIMED project, and specific demo cases. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; **R**: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative.*

Indicator	Unit	Used In Demo:	Description	Climate strategy
Total carbon removed or stored in vegetation and soil per unit area per unit time	kg ha-1 y-1	D6, D7, D8	The combined amount of carbon sequestered in both the biomass of vegetation (such as trees, shrubs, and grasses) and the soil over a specific period, measured in tons of carbon per hectare per year (tC/ha/year)	M
Tree regeneration	number ha-1	D6, D7	The natural or assisted process of new tree growth, either from seeds, seedlings, or sprouts, in a forest or woodland area. It is measured by the density of young trees (e.g., seedlings per hectare) and is an important indicator of forest sustainability, biodiversity, and the ability of a forest to recover or regenerate	R

			after disturbances like logging, fire, or disease	
Carbon storage OR Carbon sequestration in vegetation /soil	t C ha-1 or tC ha-1 y-1	D6	The process by which carbon dioxide (CO) from the atmosphere is absorbed and stored in various components of an ecosystem, in this case, vegetation in a determined area	M
Tree mortality rate	number ha-1 year-1	D6	Number of dead trees by year in a given area	R
Trees removed	Number ha-1	D6	Number of trees removed in a given area due to forest management decisions	A

3.4 Stormwater Regulation and Water Quantity and Quality

3.4.1 Indicators and Metrics

Water quality indicators are crucial for evaluating the effectiveness and impact of NBS within ecosystems. They assess how NBS mitigate water pollution, enhance hydrological cycles and restore aquatic environments. By providing measurable data on parameters such as nutrient levels, pH, turbidity, dissolved oxygen and water consumption, these indicators ensure monitoring aligns with ecosystem health, biodiversity protection and climate resilience goals. Additionally, they help monitor contamination risks, verify adherence to regulatory standards, and track sustainable water use practices.

However, incorporating water quality indicators into NBS monitoring plans presents challenges. Data collection often requires specialized equipment and expertise, especially in remote or diverse environments. Temporal variability due to seasonal changes or extreme weather events complicates consistent monitoring. Multidisciplinary approaches are essential to connect water quality results to the ecological, social, and technical objectives of NBS.

Deliverable 2.2, *"DEMOs Value Chains, Monitoring, and Validation"* (D2.2), details methodologies for selecting water quality indicators, measurement units, data collection processes, sampling frequencies, and field requirements. These frameworks emphasize the need for robust monitoring strategies. By adopting innovative solutions, such as automated sensors and stakeholder collaboration, challenges can be mitigated effectively.

By integrating water quality indicators into monitoring frameworks, NBS can demonstrate their potential to address environmental challenges while achieving co-benefits, such as reduced pollution, ecosystem restoration and sustainable water management. These indicators are essential for tracking NBS performance, ensuring compliance with regulatory benchmarks, and guiding future implementations with data-driven insights. The overall list of the indicators related to stormwater regulation and the assessment of the water quantity and quality is presented in Chapter 9 (Table 16). The following chapter presents the list of indicators that are going to be used in this project and for specific demos.

3.4.2 Reflection on specific DEMOs

All the indicators in 3.4.1 have been reviewed together with DEMO leaders. Through a series of workshops the domain experts from CETAQUA, together with local partners, identified and selected which of those indicators would be monitored, based on local specificities and needs. Those identified indicators are collected in the table below. The identified indicators are not present in the previous table to avoid repetition. A detailed monitoring plan, including the relevance of indicators, equipment needed, sampling plan and frequency is described in detail for each DEMO in Deliverable 2.2.

*Table 5: Analysis of the NBS indicators related to stormwater regulation and water quantity and quality that are going to be used in the CARDIMED project, and specific demo cases. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; **R**: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative.*

Indicator	Unit	Used in Demo:	Description	Climate strategy
Agricultural water withdrawal (AWW)	%	D1, D3	This indicator illustrates the water-food relation in terms of the percentage of agricultural water withdrawal of total withdrawal as the agricultural practices consume a significant amount of water relative to the total water consumption	M
Aquifer Surface Ratio with Excessive Arsenic (ASREA)	%	D8	This refers to the proportion of an aquifer's surface area that contains arsenic concentrations exceeding safe or recommended levels	M
Aquifer Surface Ratio with Excessive Nitrate (ASREN)	%	D1, D8, D9	This refers to the proportion of an aquifer's surface area that contains nitrate concentrations exceeding safe or recommended levels	M
Average groundwater electrical conductivity	µS/cm	D8	This indicator provides the average groundwater electrical conductivity (EC). Shifts in groundwater EC would be a sign of degradation. To be compared to a baseline	M
Avoided flooding events	%/y	D1, D2, D4	This indicator gives the number of annual floods that would have occurred without the implemented NBS	ER
Captured runoff	%/y	D2, D4	This indicator provides the runoff volume captured by the NBS, based on the NBS design capacity	A
Compliant reclaimed water (CtotalRW)	%	D1, D3, D4	Percentage of compliance with reclaimed water quality standards at the point of compliance	ER
Effective Groundwater Treatment (GWTeff)	%	D9	This refers to the processes and technologies used to remove contaminants, such as pollutants or pathogens, from groundwater to make it safe for consumption or use	A

Effective stormwater treatment (SWTeff)	%	D2, D4	Share of treated stormwater generated from stormwater treatment facilities complying with legal requirements	A
Effective Wastewater Treatment (WWTeff)	%	D1, D2, D4, D8	Share of generated wastewater that is treated in wastewater treatment facilities complying with legal requirements	ER
Effluent pollutant removal	%	D1, D2, D3, D4, D8, D9	This indicator provides an average removal ratio between incoming and outgoing pollution load. To be compared to no NBS at all or other baseline. It can be evaluated for any pollutant	M
Flood excess volume	m3	D2, D4	This indicator measures the amount of excess volume	A
Increased groundwater recharge	%/y	D1	This indicator provides information about the water volume available for groundwater recharge in comparison to the recharge without the solution, over a year	A
Infiltration rate	% or mm/h or mm/d	D5, D6, D8	This refers to the speed at which water enters and is absorbed by the soil or ground	ER
Linear Water Losses (LWL)	m^3 year-1 km-1	D2	The ratio of the volume of yearly water losses and the total length of the supply and/or distribution pipes of the utility for the assessment year	M
Physico-chemical status of groundwater/surface waters	good or poor // high, good, moderate, poor, bad	D9	This refers to the physical and chemical characteristics of water bodies, including factors such as temperature, pH, turbidity, dissolved oxygen, salinity, and the concentration of various contaminants or nutrients (e.g., nitrogen, phosphorus, heavy metals). These parameters are measured to assess water quality, ecosystem health, and the suitability of water for human consumption, agricultural use, or ecological functions, and can be categorised in a categorial scale	M
Rainfall Interception of NBS (RI)	mm/h	D1, D2, D4, D5, D6, D9	This refers to the amount of rainfall that is captured or blocked by natural features or systems, such as vegetation, wetlands, or forests, pertaining to a NBS before it reaches the ground	M

Rate of evapotranspiration	mm/m^2 day	D1, D2, D4	This refers to the combined process of water evaporation from the soil and other surfaces, and transpiration from plants, which collectively represent the movement of water from the land surface to the atmosphere	I
Reclaimed Water in non-potable Uses (RWnpU)	%	D1, D2, D3, D4, D9	The volume of reclaimed water used over the total water used for non-potable uses	A
Reclaimed Water Production (RWP)	%	D1, D2, D3, D8	Volume of reclaimed water produced (for own use or transfer to third parties) over the volume of treated wastewater or water from other non-conventional sources (e.g. stormwater)	A
Tap Water Consumption (TWC)	l/day or l/year	D9	This refers to the total volume of water used from public water supply systems for domestic, industrial, or commercial purposes	A
Water availability	m^3/y	D1, D2, D3, D4, D5, D6, D8	Water available provided by the NBS for reuse (e.g. aquifer recharge, surface discharge, ecosystem restoration, on-site reuse, etc.)	ER
Water Footprint (ISO)	m^3 m-3	D3	Water footprint associated with direct and indirect use of water for the consumption of 1m^3 of drinking water, production of reclaimed water and/or the treatment of 1m3 of wastewater. WFP is an indicator of direct and indirect freshwater resource appropriation. Directly used water is the amount used in the production/treatment, while indirect is the amount used in producing products, processes, systems, etc. that is used in the production/treatment of the product. ISO 14046 defines WFP as an indicator that quantifies the potential environmental impacts that are related to the water of a product, process or organisation. The ISO standard distinguishes water use into: **Consumptive use:** Represents freshwater that is abstracted and evaporates, that is incorporated into products or that is returned to a different watershed or the sea after use **Degradative use:** Corresponds to a degradative change in the quality of the	M

			water used and returned to the same basin here it was abstracted.	
Water Footprint (WFP-ISO)	m^3/ m^3	D1, D2	This is a standardized measure of the total volume of water used to produce goods and services, including direct and indirect water usage across the entire supply chain	A
Water Footprint (WFP-WFN)	m^3/ m^3	D1, D2, D9	This is a comprehensive measure of the total volume of water used to produce a product or service, considering the full supply chain, including direct and indirect water use	
Water provision by the ecosystem (Unavailable)	%	D1, D8	Measures the available water by the ecosystem concerning last year's availability	ER
Water Quality Compliance (WQC)	yes/no	D1, D2, D3, D4, D9	This refers to the degree to which water quality standards and regulations are met, typically assessing parameters such as pH, dissolved oxygen, turbidity, heavy metals, and microbial content	M
Water Storage Capacity (WSC)	days	D1, D2, D5, D9	The ratio between the total volume of storage (e.g. tanks for water supply, water storage from non-conventional sources such as rain harvesting systems, reclaimed water storage) and the average flow provided or demanded to the considered system (demands associated with distribution systems, rain harvesting systems, treatment plants, etc.)	ER
Water-related materials' Recovery (WR)	%	D9	By-product material or waste that is recovered and is suitable for reuse after a treatment process or activity to enhance other activities within the site of interest and the organization's scope	A

3.5 Heat Mitigation

3.5.1 Indicators and Metrics

Heat indicators are essential in evaluating and monitoring the effectiveness of Nature-Based Solutions (NBS) in mitigating urban heat and enhancing thermal comfort. As cities face increasing temperatures due to climate change and the Urban Heat Island (UHI) effect, addressing heat-related challenges becomes a critical component of sustainable urban development. Indicators such as air temperature at pedestrian level, green space connectivity, and tree shade coverage offer valuable insights into the thermal benefits provided by NBS and their contributions to public health, biodiversity, and overall urban resilience.

Heat indicators help quantify the capacity of NBS to moderate urban temperatures, reduce heat-related health risks, and improve human comfort. By monitoring metrics like temperature reduction, the extent of tree cover, and green-blue infrastructure proportions, stakeholders can evaluate how NBS interventions such as urban greening, and tree planting mitigate extreme heat events and enhance thermal comfort. These indicators also highlight co-benefits, including improved air quality, noise reduction, and increased biodiversity, strengthening the case for integrating NBS into urban planning.

Incorporating heat indicators into NBS monitoring plans presents several challenges. One major issue is the variability in data collection methods, which may require advanced tools like remote sensing, climate modelling, or ground-based sensors. Temporal and spatial variability in heat dynamics complicates consistent measurement, while the influence of external factors, such as urban morphology and socioeconomic patterns, can make it difficult to isolate the specific contributions of NBS.

By effectively monitoring heat indicators, cities can better understand and maximize the benefits of NBS in creating cooler, healthier, and more liveable urban environments. This knowledge supports evidence-based policymaking and fosters resilience to the escalating impacts of climate change.

3.5.2 Reflection on specific DEMOs

All the indicators in 3.5.1 have been reviewed together with DEMO leaders. Through a series of workshops the domain experts from CREAF, together with local partners, identified and selected which of those indicators would be monitored, based on local specificities and needs. Those identified indicators are collected in the table below. The identified indicators are not present in the previous table to avoid repetition. A detailed monitoring plan, including the relevance of indicators, equipment needed, sampling plan and frequency is described in detail for each DEMO in Deliverable 2.2.

*Table 6: Analysis of the NBS indicators related to heat mitigation that are going to be used in the CARDIMED project, and specific demo cases. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; **R**: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative.*

Indicator	Unit	Used in Demo:	Description	Climate strategy
Air temperature at pedestrian level (daytime and night-time)	°C	D4, D5, D6	The average temperature reported at pedestrian height, during day and night	M
Concentration of PM_{10} and $PM_{2.5}$, NO_2, and O_3 in ambient air	[μg/m^3]	D5	Daily means observed at urban background stations or measured in the NBS	A
Daily temperature range	°C	D4, D5, D6	Calculation of the variations in the temperature within an area	M
Days with temperature >90th percentile, TX90p	%	D4, D5, D6	The percentage of days in a given period of time when the temperature exceeded the 90th percentile of the baseline reference period	M
Heatwave risks (number of combined tropical nights (>20ºC) and hot days (>35ºC))	Numbe r of days/y ears	D4, D5, D6	Assess the number of days here extreme temperatures were reported. The tropical nights are estimated when minimum temperatures do not drop below 20°C. The hot days are estimated when maximum temperatures exceed 35°C	M

Mean or peak daytime local temperatures (°C)	°C	D4, D5, D6	Measures the average or highest daytime temperatures experienced in a specific area for a defined time period	M
Monthly mean value of daily maximum temperature (TXx)	°C	D4, D5, D6	Calculates the average of the highest daily maximum temperatures recorded on a monthly basis	M
Monthly mean value of daily minimum temperature (TNn)	°C	D4, D5, D6	Presents the average of the lowest daily minimum temperatures recorded each day within a month	M
NDVI	-1 to 1	D5	Monthly data on NDVI should be collected. The normalized difference vegetation index (NDVI) is a widely used metric for quantifying the health and density of vegetation using sensor data. Higher values (0.4 to 0.9) show lands covered by green, leafy vegetation and lower values (0 to 0.4) show lands where there is little or no vegetation. Negative values tend to indicate the presence of water, clouds or snow. It's a measure of vegetation cover	A
Number of trees	Numbe r	D5, D6	The number of trees in a city provides valuable information such as air quality improvement, heat island mitigation, water management... The measurement should be done before and after an NBS and ideally annually taken	M
Recreational opportunities provided by green infrastructure	Interac tions/ week	D5, D6	Recreational opportunities provided by green infrastructure are important for several reasons, encompassing physical health, mental well-being, social cohesion, economic benefits, and environmental sustainability	A
Self-reported well-being/ Good Moods in the ECS Garden		D5, D6	Citizen science: How do you feel when you arrive, when you are in the ECS, when you leave? How important is the ECS for your general feeling of well-being? (we can analyze links to the frequency of visits, employment status, a feeling of social connectedness etc.)	A
Relative humidity		D5, D6	Data required for the calculation of other indicators	I

3.6 Energy

3.6.1 Indicators and Metrics

Energy indicators are critical in the evaluation and monitoring of NBS because they provide insights into the energy dynamics associated with implementing, operating, and maintaining these solutions. As the transition to sustainable and resilient urban and natural systems gains momentum, the role of energy efficiency and renewable energy in NBS becomes increasingly prominent. Indicators such as energy consumption, avoided emissions, energy savings, and renewable energy generation become key tools to measure the performance and environmental impact of NBS, aligning with broader sustainability goals, such as climate change mitigation and resource efficiency.

Energy indicators enable stakeholders to quantify the benefits of NBS, such as reducing energy demands for cooling and heating through enhanced vegetation or generating renewable energy through biogas production and combustion systems. These metrics are vital for decision-making, as they allow policymakers, planners, and researchers to assess trade-offs, justify investments, and benchmark NBS against convention and existing infrastructure. In addition, energy indicators contribute to the understanding of co-benefits, such as decreased greenhouse gas emissions and use of groundwater in water-scarce areas; thus, amplifying the broader environmental, social, and economic value of NBS.

Incorporating energy indicators into the monitoring plans of NBS presents challenges. One major issue is the variability in data availability and quality, as energy-related data often require specialized equipment or models. The integration of energy metrics with other environmental and social indicators can also be complex, demanding interdisciplinary approaches and standardized methods. Additionally, the temporal and spatial heterogeneity of NBS makes it difficult to generalize findings or scale up results from pilot projects to larger-scale implementations.

Finally, the dynamic nature of urban environments, where multiple factors influence energy consumption and savings, requires robust and adaptable monitoring frameworks to isolate the impacts attributable to NBS. Overcoming these challenges necessitates a concerted effort to harmonize monitoring protocols, invest in data collection infrastructure, and foster collaboration across sectors.

By addressing these challenges and effectively employing energy indicators, NBS can be optimized to contribute meaningfully to energy efficiency and sustainability objectives, paving the way for greener and more resilient futures. Thus, the list of indicators reported in Chapter 9 (Table 18) is keen on presenting quantified methods of assessing the impact of NBS related to energy consumption. The following chapter presents the list of indicators that are going to be used in this project and for specific demos.

3.6.2 Reflection on specific DEMOs

All the indicators in 3.6.1 have been reviewed together with DEMO leaders. Through a series of workshops the domain experts from IMPERIAL, together with local partners, identified and selected which of those indicators would be monitored, based on local specificities and needs. Those identified indicators are collected in the table below. The identified indicators are not present in the previous table to avoid repetition. A detailed monitoring plan, including the relevance of indicators, equipment needed, sampling plan and frequency is described in detail for each DEMO in Deliverable 2.2.

*Table 7: Analysis of the NBS indicators related to energy consumption that are going to be used in the CARDIMED project, and specific demo cases. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; **R**: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative.*

Indicator	Unit	Used in Demo:	Description	Climate strategy
Air temperature (Tair)	ºC	D5, D9	Assessment of the ambient temperature, which impacts the energy demands	M
Air temperature reduction	ºC	D6	Calculation of the temperature reduction as an indication of the applied NBS solution. This indicates energy demand	M

Biogas generation due to wastewater treatment	MJ/m^3 wastewater	D1	Indicator of assessing the production of biogas, generated as a by-product of the anaerobic digestion in wastewater treatment. This indicator reports the potential of using wastewater facilities for renewable energy production	M
Biogas generation due to wastewater treatment	m^3 biogas/$m^{3;}$ wastewater	D8	Indicator of assessing the production of biogas, generated as a by-product of the anaerobic digestion in wastewater treatment. This indicator reports the potential of using wastewater facilities for renewable energy production	M
Building Energy Performance	kWh/m^2	D4	Energy consumption per square meter of floor space	M
Building temperature behaviour	°C in one year	D4	Fluctuation of temperature in one year of a building	M
Cooling / Heating	%	D6	Reduction in energy use for cooling/heating due to NBS, e.g. green wall	M
Direct energy usage in food production	MJ	D3, D6, D9	Energy used by food systems directly	M
Electricity use in agriculture	kWh/m^2 or ha	D1, D7, D9	Energy use in agriculture points to the energy-food relation by illustrating the total energy demand per land surface	A
Energy Consumption for Wastewater Treatment	kWh/m^3 wastewater	D1, D2, D3, D4	Energy used per cubic meter of wastewater treated	M
Energy footprint	MJ	D1, D3	Defined by The Global Footprint Network (GFN) (2009) as the sum of all areas used to provide non-food and non-feed energy	M
Energy for water treatment	kWh/m^3 wastewater	D9	Measures the energy consumed during the water treatment. This indicator evaluates the energy efficiency of the wastewater treatment	M
Energy intensity of water supply	kWh/m^3 water	D3	This indicator represents the quantity of energy to supply one cubic meter of water to urban areas regarding the energy-water relation	M
Energy use in agriculture	MJ/Calories of food	D1	Indicator that points to the energy-food relation by illustrating the total	M

			energy demand per calories of food products	
Energy use savings due to NBS implementation	kWh/y	D3	Calculation of energy reduction as an outcome of the deployment of a specific NBS	M
Increase in local renewable energy production	% in kWh	D9	Percentage increase in the share of local renewable energy due to the project	M
Renewable energy share	%	D3	The percentage of the total energy consumed by renewable resources	M
Urban heat reduction	%	D4	Reduction of heat in cities	M
Operational Energy Consumption	kWh	D1, D2, D6	Measures the total energy used during the operation of a system or an infrastructure	M
Water-Energy-Food-Carbon Footprint of the Integrated System	0-100 scale	D3	Combined Index: A dimensionless score or weighted index that integrates the footprints (such as a 0–100 scale)	M
Energy Saving from Rainwater Removed from Combined Sewer	kWh	D3	Assessment of the reduction in energy consumption by diverting rainwater from the respective facility	A
Gross Renewable Consumption Relative to Total Gross Final Consumption	%	D3, D9	Measures the share of renewable energy compared to the total energy consumption	M
Increase in Renewable Energy Use in the Area	%	D3, D9	Percentage of adoption the renewable energy use within a specific area	M
Electricity consumption during the construction stage (in terms of working hours)	kWh/day	D4	Daily electricity consumption. It can also be normalized by working hours. In this case, the unit used will be hours (h)	M
Electricity consumption during urgent irrigation purposes	kWh	D4, D5	Electricity used for irrigation	A
Energy Consumption of Biogas Production System	kWh	D8	Electricity used for biogas generation (and possibly biogas upgrade)	M

PV Electricity Generation and Total Land Used	kWh/m^2	D8	The amount of electricity generated from the photovoltaic panels	M
Air Humidity	%	D9	The ratio of the current water vapour in the air to the maximum amount of water vapour the air can hold at a given temperature	I
Energy consumption of Water Storage and Irrigation in green areas	m^3/m^2	D9	Estimation of the energy used for water storage and irrigation in green spaces	A

4 Data Collection Strategy

4.1 Data Mapping Methodology

This chapter aims to introduce the Data Landscape Playbook (DLP) methodology (Gitbook.io, 2021) that will be used as a guideline for the data collection strategy. In particular, DLP endeavours to synthesise the data ecosystems and thus understand how these data sources are currently being accessed, used stored and shared, in order to identify any potential areas for improvement or potential risks. Leveraging graphical interpretations, DLP assists either single organisations or cross-sectional consortiums to acknowledge the data value they own and to which extent this can be improved in order to achieve the ultimate impact. Thus, in the CARDIMED project, this method will be used in order to facilitate the generation of a detailed report on the identified data sources and the bespoken data integration plans for each demo case, so as to fulfil the requirements of the WEFE Nexus models (WP5), and the assessment of the NBS indicators, as they have been specified in T4.1 and T2.2 (*D2.2 – "DEMOs value chains, monitoring & validation"*). Figure 3 presents the key benefits of the DLP.

This methodology has been already articulated in two EU-funded projects, called the Urban ReLeaf project (GA No. 101086638) and THETIDA (GA No. 101095253). To avoid repetitions, our intention will be mostly focused on the outcomes of this process, which will be reflected in Chapters 5 and 6. The following sections aim to provide a quick overview of the main steps of DLP methodology. Since the majority of the DEMO cases are in the process of defining the different equipment that is planned to be used, subsequent changes are foreseen on these early shaped data ecosystem maps. Nevertheless, the purpose of this analysis is to set the guidelines with respect to the data integration plans that can be adopted, so as to ensure that any additional data stream will be compliant with the proposed strategy. Any additional reported dataset will be reported in the upcoming Data Management Plan (D1.3, M54).

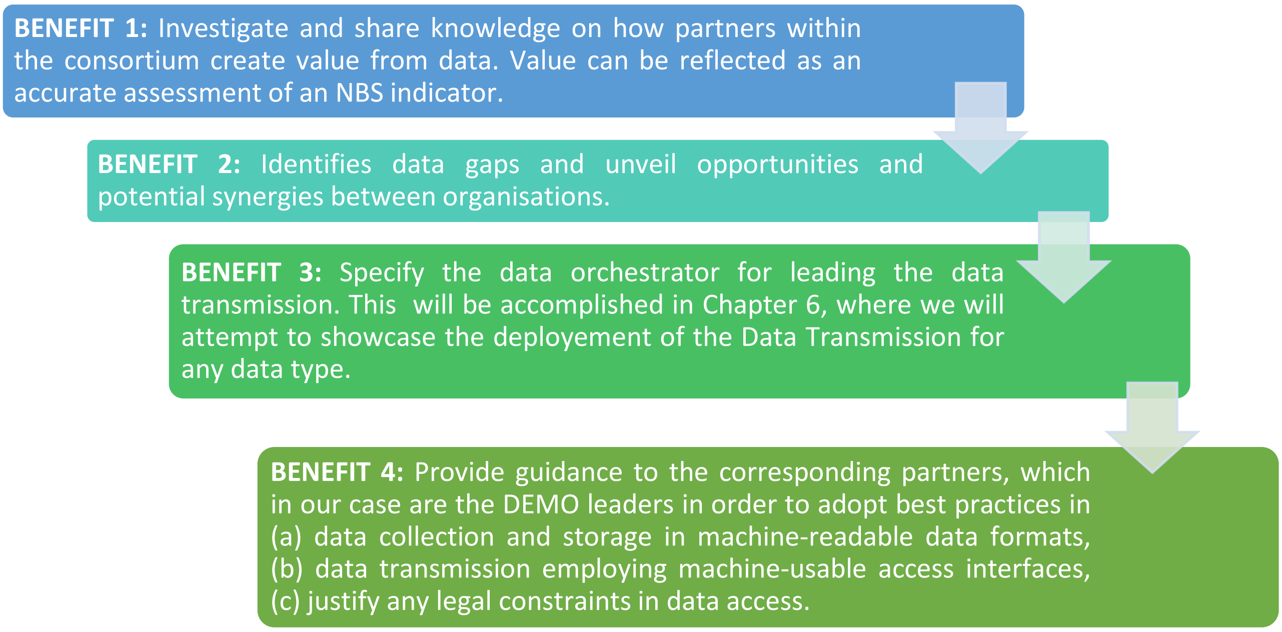


Figure 3: Key benefits of employing the Data Landscape Playbook methodology in the Data Collection Process.

As presented in Figure 4, the DLP consists of four main steps, called Plays. The first step (**Play 1**) attempts to explore how data could address a research problem. For this purpose, extensive work has been undertaken (Task 4.1) to generate a comprehensive list of indicators covering the biodiversity, food and soil quality, and the water quality and quantity and energy domains. This generalised list was further narrowed down in order to be aligned with the specificities of each demo case (Chapter 3). Furthermore, the second and third steps (**Plays 2 and 3**) aim to synthesise the Data Ecosystem Mapping and the Data Infrastructure for each demo case and thus describe the data owners, formats and access interfaces. To investigate the spatiotemporal requirements of the WEFE Nexus models, we expanded this methodology and thus examined the spatiotemporal characteristics of the reported data streams. Finally, **Play 5** reviews the technical and legal openness, as suggested by the Data Spectrum, in order to evaluate especially for the datasets stewarded by organisations outside of the CARDIMED consortium the terms of use and modification. Additional attention was given to the open-access licenses, wherever applicable. The full extent of this analysis is foreseen to be applied in the final version of the data management plan (D1.3), which is planned to be delivered in M54. This deliverable is expected to influence the outcomes of several tasks, as it will affect the integration with the MW (T4.4), all five digital tools (T4.5), the accurate assessment of the impact of NBS solutions in certain indicators (WP5), as well as the pilot demonstrations (WP6).

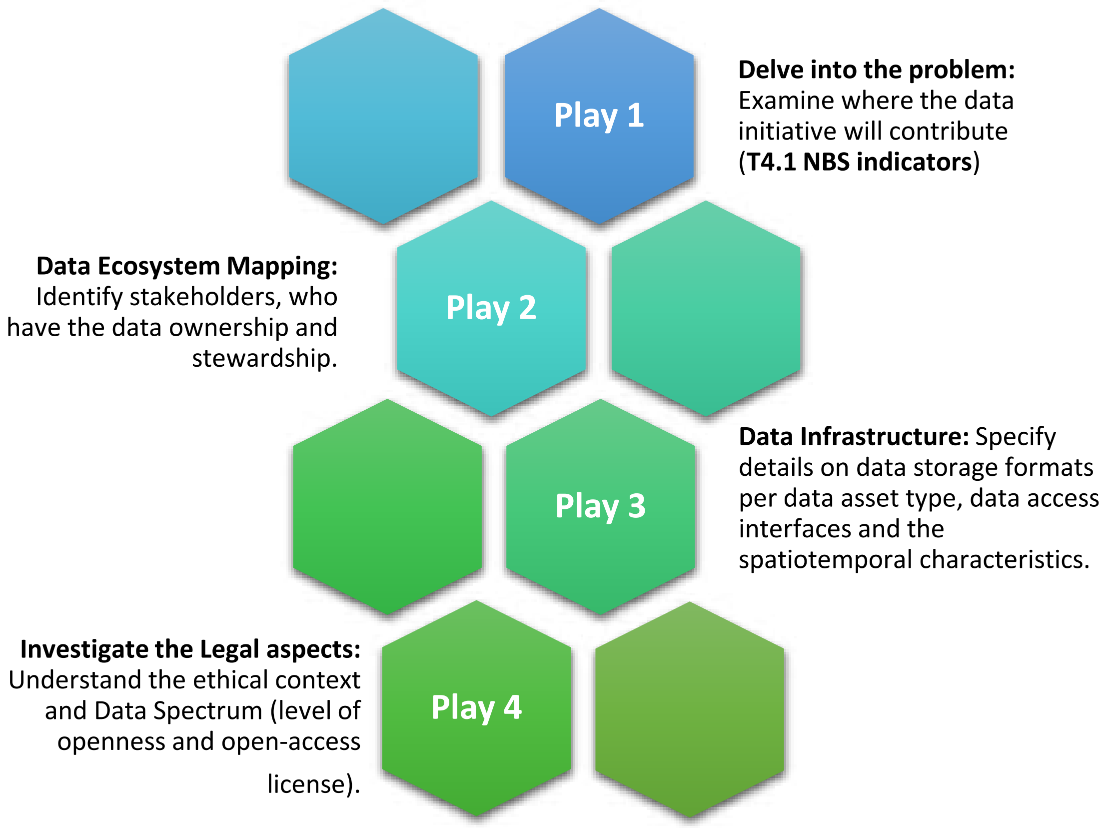


Figure 4: The four main pillars of the Data Landscape Playbook Framework as imposed by the ODI.

4.2 Data Ecosystem

The CARDIMED project aims to develop a collection strategy integrating data streams spanning different spatiotemporal and thematic scales that (a) have already been collected, (b) will continue to be collected and (c) are planned to be collected during the initiation of the pilots (WP6). All these data will serve the monitoring of the different NBS solutions that will be applied covering various aspects in the sectors of food, water, biodiversity and energy. Figure 5 illustrates the ecosystem of the CARDIMED project, and in particular the applied NBS in the nine DEMO cases. As depicted, in some cases, there is an interconnection between NBS solutions and the regions, indicating their demonstration in more than one region. All these regions could be envisioned as living local-based data pools, as various collections will be facilitated using in-situ sensors, field sampling campaigns, citizen science-driven monitoring and aerial inspections. The local scale data streams will be supported in some demo cases (e.g., DEMO 1, 5, 6 and 7) by regional datasets arising from Earth Observation (EO) spaceborne constellations supporting the assessment of the positive impact gained from the deployment of the climate-resilient solutions.

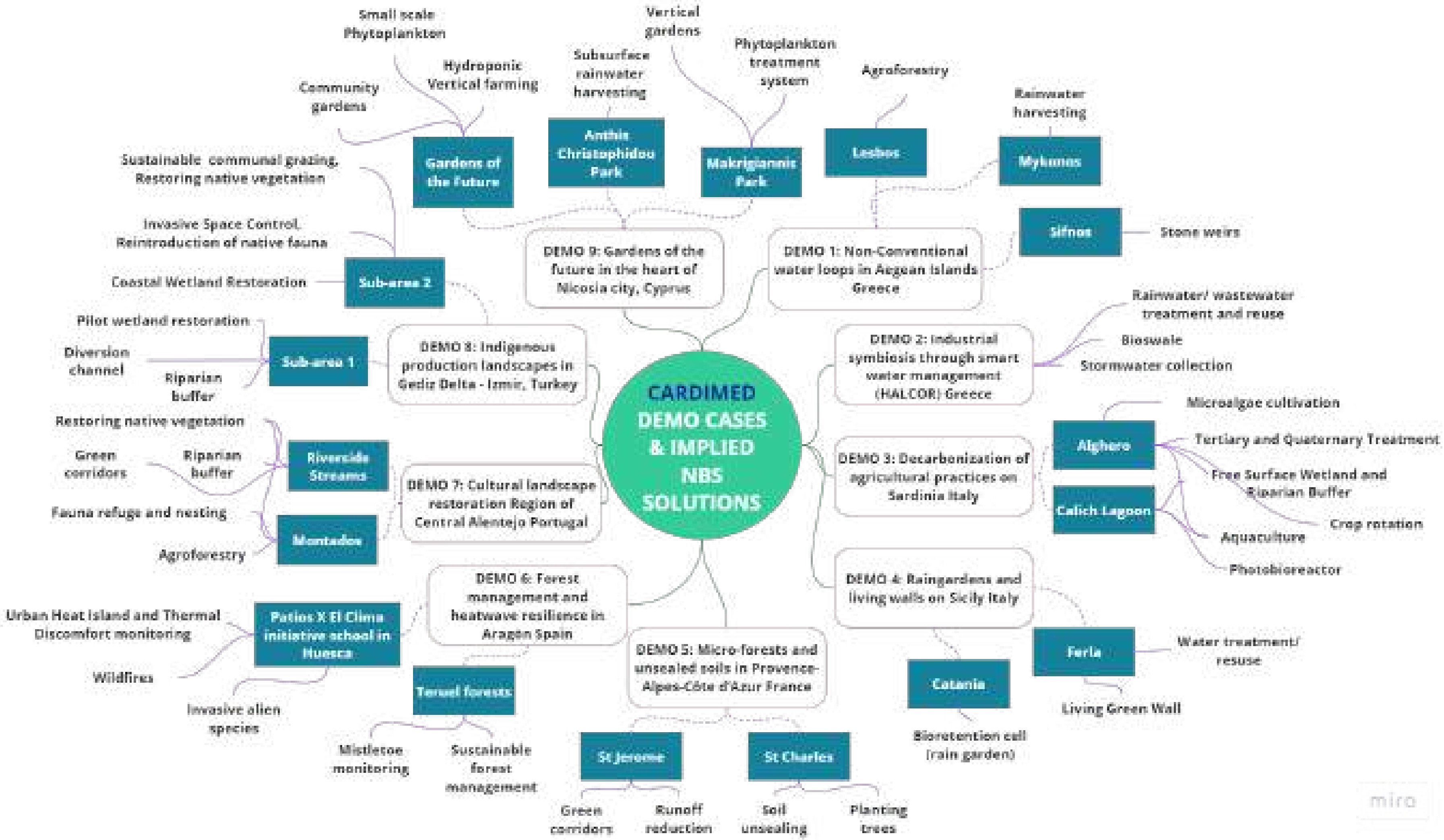


Figure 5: High-level presentation of the DEMO and sub-DEMO cases of the CARDIMED project. In the centre of the diagram, we present the whole project, which is divided into nine demo cases. In the third layer, the respective sub-demos are presented spanning different locations, where the NBS solutions will be applied.

Before delving into the design of the data ecosystems, it is essential to define the various data types that have been reported by the DEMO and sub-demo leaders, as in most cases these data types require different integration mechanisms due to different spatial and temporal characteristics, data structure formats and accessibility interfaces. This exercise enables the design of different data integration strategies per data source. The outcome of this analysis is reflected in Chapter 6, which provides demo-specific integration plans tailored to the specified data types. The following chapters therefore aim to address the aforementioned peculiarities and denote the different types that the CARDIMED project plans to use.

4.2.1 Guidelines for Static Data and Geospatial Historical Data Integration

In the context of the project, we faced several cases of data streams that should be ingested only once as they will only serve the purpose of intermediate layers or will be stored as a knowledge database. Nevertheless, both data sources are considered pivotal assets as they allow us to have a clear understanding of the DEMO cases, their peculiarities in terms of the socio-environmental characteristics, the climate change risks that they are facing and any historical results on the NBS solutions. Thus, the following sections aim to define both categories and high-level suggestions for data integration, as they differ significantly in terms of their data format, accessibility and their primary purpose of existence within the project.

4.2.1.1 Definition of Static and Geospatial Historical Data

We denote **Static datasets** as the ones that present information in non-machine-usable formats and thus hamper any fast and easy data extraction, processing and effortless integration with other systems. Indicative examples of such cases are PDFs, scanned documents, and unstructured text files. For example, reported cases of such data sources are DEMO 1 (sub-demo 1.3) and 8, with the first covering an extensive hydrological and hydraulic analysis and flood risk assessment of the river basins of the Aegean Islands hydrographical district (EL14). Furthermore, Demo 8 refers to old field campaigns and the investigation of the number of species in domestic animals. In general, this data type usually reflects historical reports, environmental assessments and other records that can contribute by providing valuable background information and observations on the local existing conditions of the DEMO cases.

On the contrary, **Geospatial Historical Data** represents datasets that are accompanied by geographical information and are usually stored in machine-usable data formats. However, they have been created during older surveys or research initiatives and either there is no intention to update such kind of data or is generated with sparse temporal frequency. Indicative examples of these datasets are presented below.

- **ESRI Shapefiles:** Vector datasets in point, polyline or polygon, arising from a geographic information system (GIS) software. These data formats might describe static digitalised datasets, e.g., the campus map of (DEMO 5), the Local Climate Zones map (DEMO 5), and Intensity-Duration-Frequency (IDF) curves for precipitation data hyetograph production (DEMO 1), which have been produced in the past and we don’t have clear evidence of the reproduction of this specific data from the data owner.
- **GeoTIFFs:** Geospatial Raster data arising from EO surveys or multilayer geospatial analysis. Such cases are the Land Use/Land Cover (LULC) from the Copernicus service, which is produced every six (6) years, the European Soil Database, Soil Bulk Density in Europe, Global Rainfall Erosivity Database (GloREDa), Topsoil physical properties for Europe (based on LUCAS topsoil data), European Soil Database Derived data and Orthophotos and Digital Elevation Models (DEM) from cadastral surveys, which are randomly updated.
- **CSVs (Comma-Separated Values), ASCII/TXT files:** Tabular data format that includes results from a laboratory analysis or on-the-field data collection campaigns. In some cases, these datasets are accompanied by the coordinates of the places where the sampling activity has taken place, in other cases the definition is more generic and normally describes the wider extent of the investigation area.

This kind of data provides a rich source of quantitative and spatially-reference information, which is stored already in machine-useable data formats and does not require any intensive integration effort, as in some cases they are provided through already established web services.

4.2.1.2 Integration Plan for Static and Geospatial Historical Data

For the CARDIMED project, **static data** will not be seamlessly integrated into the middleware to be used for any kind of computational analysis, they hold qualitative information that can potentially assist in contextualizing the upcoming results received during the pilot demonstration activities. This material will Figure 6 will be uploaded to the centralized file server of the middleware (MW) platform of CARDIMED and be accessible through the visualisation interface of the platform (see Figure 5)

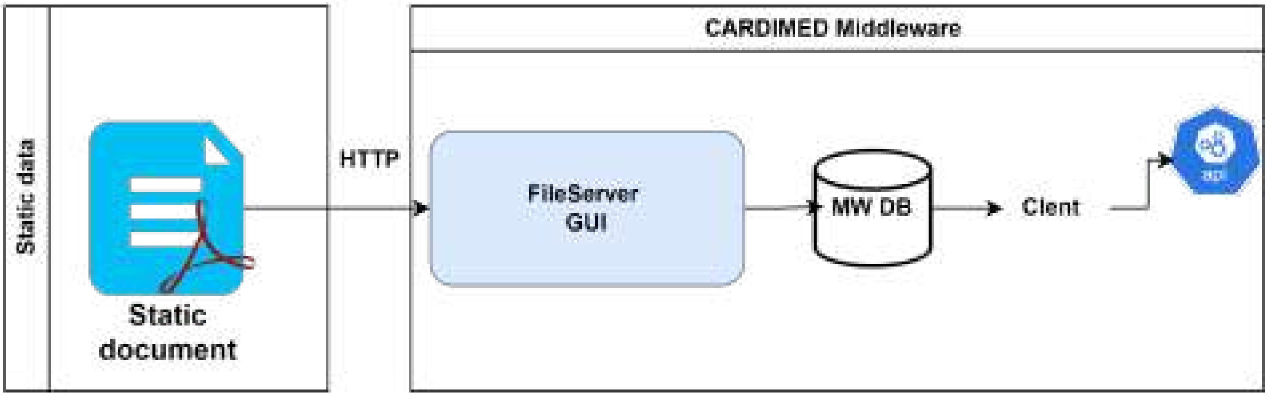


Figure 6: Indicative example of static data ingestion in the MW of CARDIMED. This integration imposed the necessity of a manual upload by a responsible actor (see additional examples in Chapter 6).

Furthermore, the integration of the historical data might vary significantly based on the infrastructure that has been chosen for data storage and accessibility. Examples of the adopted interfaces are Open Data Platforms, Spatial Data Catalogues, Open Geospatial Consortium (OGC)-compliant web services, e.g., Web Map Services (WMS), Web Feature Services (WFS), Web Map Tile Services (WMTS), and offline and locally stored laboratory measurements. Figure 7 presents the different integrations that will be adopted for the historical datasets.

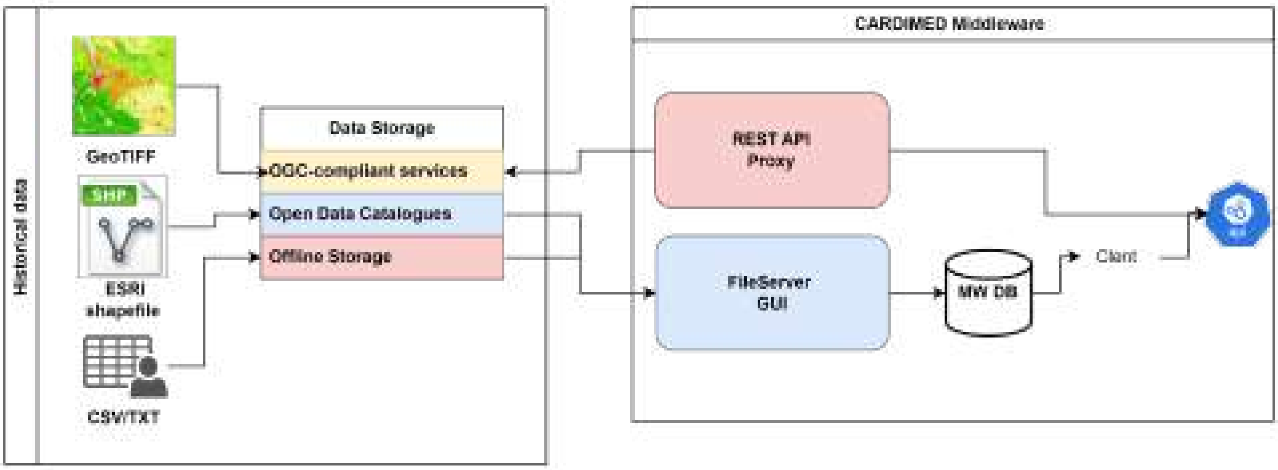


Figure 7: Examples of the different integrations that will be adopted for the historical datasets.

4.2.2 Guidelines for Data Integration of Laboratory Data

Laboratory analysis fulfils a crucial role in the CARDIMED project as it enables the identification of valuable parameters that are related to water quality and environmental monitoring and thus will provide us with actionable insights regarding the impacts of NBS implementations. Regular sampling campaigns will be initiated during the pilot demonstrations so as to investigate NBS parameters that are relevant to water reuse, rainwater harvesting, aquifer recharge, microalgae cultivation, wetland monitoring, etc. Detailed analysis per

DEMO is provided in Chapter 5. The following sections aimed at shedding light on the main laboratory variables that will be extracted and how they will be transmitted to the MW platform of the project.

4.2.2.1 Laboratory data streams

The laboratory data sources will substantially contribute to various NBS applications across CARDIMED DEMO sites, targeting the inspection of the environmental and water management treatments. A synopsis of the targeted variables that will be produced is given below. The following measurements will support DEMOs 1, 2, 3, and 9.

- **Physicochemical parameters:** Refers to the temperature, pH, alkalinity, turbidity and conductivity variables, which provide indications of the water treatment.
- **Biological and microbiological indicators:** Identify the presence of microorganisms and bacteria, such as Escherichia coli (E. coli), Legionella (genus of bacteria commonly found in freshwater), Nematode (roundworm type found in water and soil) and Salmonella (A genus of bacteria that can cause foodborne illness) that affect the soil and water quality.
- **Metal and Ion Concentrations:** Metals such as cadmium, anions and cations can indicate the adoption of unsustainable water management practices and the existence of harmful contaminants in the water.
- **Oxygen, Nitrogen and Phosphorous concentrations:** Describes parameters of Dissolved Oxygen (DO), oxidation-reduction, and nitrogen compounds (e.g., NH4-N, NO3-N, TN, PO4-P, etc.) that give insights about the biochemical processes that impact water quality.

4.2.2.2 Integration Plan for Laboratory Data Streams

The integration of the laboratory data streams will follow the same process as the one presented in Chapter 4.2.1.2, specifically the data transmission flow of the CSV offline data (see Figure 7). In general, laboratory analysis is a process that lasts in normal conditions for 1-2 weeks by experienced personnel, preventing this way any automated and seamless data uploading. To accommodate these data types, a centralised secured file server will be deployed with a graphical user interface (GUI), which allows the responsible actors to upload the results from the analysis without any time constraints (expected to be further described in the upcoming D4.2, M36). All DEMO cases will store this information in either CSV or Microsoft EXCEL data formats.

4.2.3 Guidelines for IoT Data Integration (In-Situ Sensors & Citizens-Science)

Within the context of the CARDIMED project, in-situ IoT data streams and Citizen Science data represent two dynamic sources of information, which contribute to the continuous monitoring of environmental and social impacts of NBSs in DEMOs. These data streams are generated through pre-installed in-situ sensors in different positions (e.g., soil, at the vicinity of a water course, in drilled boreholes or at positions 1.5-2m above the surface) or during citizen science campaigns and provide real-time, near-real-time or on-demand observations, covering a wide range of variables or provide citizen feedback, enhancing the project's capacity for monitoring of the effectiveness of NBSs. The following sections aim to define both data streams and the suggested data integration plans for each type.

4.2.3.1 In-situ IoT sensing monitors and Citizen Science (CS) data streams

The in-situ IoT sensing-driven data streams describe the collection of real-time or near-real-time data from the demo sites through single sensors or a network of sensors. The majority of the sensing devices are planned to be purchased and installed in 2025 for various cases, nevertheless existing sensing networks have already been reported in DEMOs 1, 5 and 9. Examples of in-situ data collection in CARDIMED include:

- **Water quality and level sensors:** Monitoring parameters such as pH, turbidity, conductivity, flow rates, water levels, etc. in water bodies, wetlands, aquaculture cultivation areas, water tank level measurements, water storage quantity, etc. to assess the impact of NBS interventions (e.g., wastewater reuse, rainwater harvesting, rainwater and surface runoff collection, etc.).

- **Soil sampling sensors**: Collect soil health indicators, including moisture levels, soil carbon content, and nutrient concentrations. These data will be particularly collected in pre-determined soil sampling campaigns in pilot areas of DEMOs 1, 2, and 7.
- **Meteorological sensors**: Capturing measurement of temperature, relative humidity, wind speed and directions and air pressure. The microclimatic conditions around NBS areas are going to be collected using low-cost sensors and the existing network of professional sensors owned by local stakeholders.
- **Biodiversity sensors and static cameras:** Capturing the presence of fish or the presence and changes of fauna and flora species and numbers in an inspected area. These technologies will be used for capturing changes over time.

Furthermore, we consider the data streams arising from citizens to be similar to the sensor-driven data as they are normally collected with the active participation of citizens using low-cost wearable devices or mobile applications and thus contain geolocalised information with the addition of geotagged photos or unstructured content to be coupled with the positional data. In the CARDIMED project, citizen science (CS) data is expected to capture local insights, perceptions and observational data on the efficiency of the deployed NBS, enriching this way the democratization of the project's objectives to the wider local communities. The key types of CS data include:

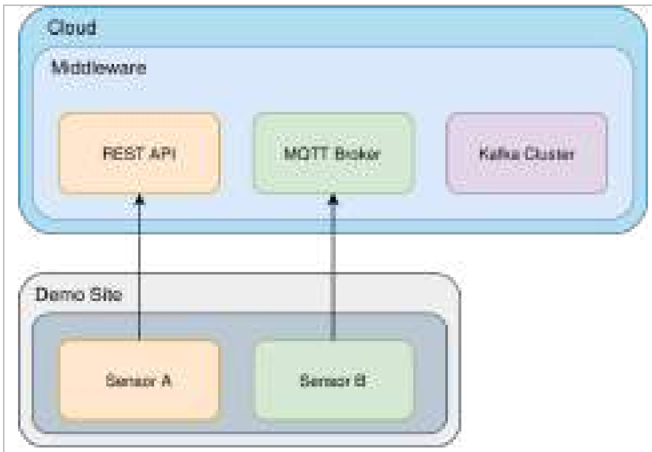
- **Biodiversity observations:** Participants can capture and share sightings of various species of fauna and flora, helping track biodiversity and assess the ecological impact of NBS solutions.
- **Perceptions of NBS benefits:** Using the user engagement app developed in Task 4.5.3, citizens can visit specific locations where NBSs are present and share their subjective beliefs on the benefits of NBSs leveraging gamification elements.
- **Climate Event Reports:** Citizens report on the local intensity and frequency of climate events, such as floods, heatwaves, and droughts through the engagement app. These reports provide situational awareness and help identify areas most affected by adverse climate conditions.

Upon the successful data storage of the CS data in the MW data platform, subsequent data aggregation methods will be applied in order to reveal trends, patterns, and spatial hotspots of adverse environmental effects, as well as to capture community perceptions and priorities over the deployed NBSs, highlighting the specific needs of the local communities.

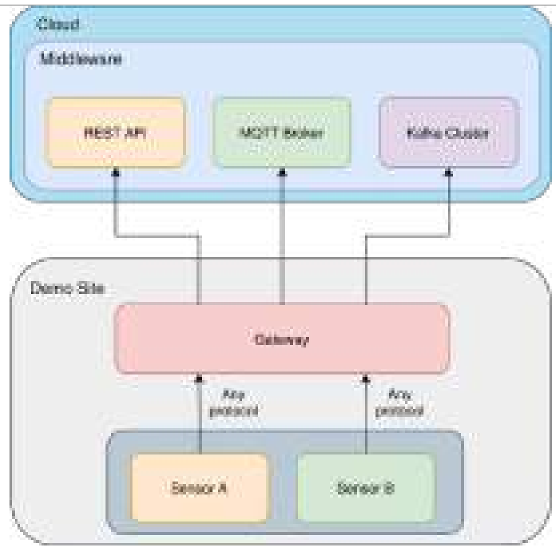
4.2.3.2 Integration Plan for IoT and CS data streams

In the current project, JSON is the most recommended data format for IoT and Citizen Science in-situ data integration into the CARDIMED project due to its versatility, a wide range of supported libraries, simple usage behavioural characteristics, and ability to handle complex data structures such as strings, numbers of arrays, and objects. This is due to its flexible structure that facilitates the interchanging of data from different sources in an efficient way. JSON has been also designed for general use, as processing tools supporting it, thus enabling smooth interfacing between the different components of CARDIMED. Additionally, Microsoft EXCEL, CSV, and XML can be also used as an alternative for tabular data, especially when a single-variable or export-friendly dataset with a relatively simple domain is suitable.

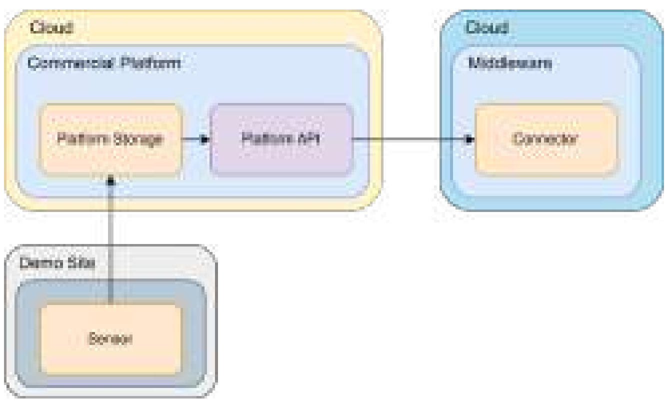
Lightweight protocols such as MQTT will be used for data transmission and integration as they are declared as an efficient messaging environment between connected devices with less bandwidth ideal for IoT sensors. An MQTT message broker will exist in the MW platform, allowing for the IoT system to publish data messages on a specific topic. It is appropriate for continuous environmental monitoring where the volume of data and speed of transmission are important. For web-based data access (i.e., HTTP), RESTful APIs will be also exploited due to their simplicity and popularity as a common standard for data exchange between web services. Apache Kafka orchestrator will run on top of the message broker, facilitating this way a large scale of handling distributed data streaming and asynchronous communication, between the different data streams coming from either a network of sensors or citizen science applications (Streamnative.io, 2019). Nevertheless, the combination of these protocols allows CARDIMED to establish a scalable data ecosystem architecture for efficient and real-time data integration, and analysis. Figure 8 presents the different options for data transmission covering both the in-situ data streams and the citizen science-driven data streams, exploring four cases (a) the data transmission directly from the sensor as it is often coupled with an IoT SIM card enabling the data transmission through General Packet Radio Service (GPRS) or Long-Term Evolution (LTE) or a data logger that supports the same wireless transmission over these cellular networks, (b) the existence of a gateway, (c) the interconnection with a third party platform, and (d) the transmission of data that will be collected during the citizen science campaigns in the respective demos. The latest is always supported with a 4G (LTE) cellular network in order to transmit the data to the backend of the digital tool provider. As the MW platform can support several intercommunication protocols, the specific digital tool providers can be flexible and transmit the geolocalised unstructured data either using a publish/subscribe (Pub/Sub) or a client-server protocol.



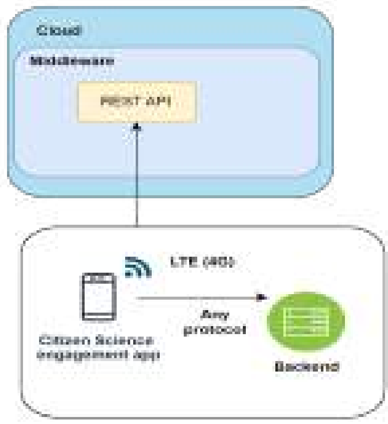
(A) Data transmission from the sensors. Three types of communication protocols can be adopted, the lightweight Pub/Sub MQTT, the client-server REST API, and the Kafka orchestrator.



(B) Data transmission from the sensors through the gateway, which acts as an intermediate layer for wireless or wired data transmission. Similarly, as in A, all three communication protocols can be supported.



(C) Data transmission through a commercial third-party platform, which acts as an intermediate layer, often supported by an Application Programming Interface (API). The MW connector will perform GET requests to



(D) Data transmission through the citizen science engagement app to the MW platform.

retrieve the observations from the data storage using the HTTP protocol.	

Figure 8: Integration of in-situ sensors and citizen science-driven data to the MW platform of CARDIMED following different data transmission and intercommunication protocols, or intermediate layers.

4.2.4 Guidelines for EO Data Integration

Besides the on-the-ground data collection activities that were described in the previous sections, CARDIMED will capitalize on multisensory EO data streams arising from both spaceborne constellations and drone/airborne mission campaigns. For the latest, we foresee exploring data capabilities with Very-High-Resolution (VHR) passive or active satellite images from the Contributing missions of Copernicus. In the following sections, brief descriptions are provided for the EO data streams that will be used and the data integration plans.

4.2.4.1 Satellite, Airborne/drone-driven data streams

Earth Observation data streams will be explored in the CARDIMED project in order to measure the positive impact of the deployed NBS solutions (e.g., the reshaping of the unsustainable waterproof asphalt with porous/pervious asphalt with urban micro-forest presence in DEMO 5) in the reduction of heat extremes that affect most of the urbanised environments of the southern European cities, or mitigate the surface runoff that helps to prevent flash flood events. Addressing these needs, EO datasets will be primarily harvested from the Copernicus Data Space Ecosystem, where several EO satellite missions are distributed to the public free of charge. The same infrastructure also supports the acquisition of VHR data coming from the contributing missions. In handpicked cases (e.g., DEMOs 1, 4, and 5) multispectral, LiDAR and DEM VHR data streams collected from airborne, or drone surveys will complement the data ecosystem of the project.

Concerning the satellite-driven data sources, CARDIMED will capitalise on the Copernicus program and in particular on the multispectral mission of Sentinel-2 in order to assess the vegetation cover, land-use changes and the presence of urban heat island effect, and other potential variables that provide a solid source of knowledge regarding the surface characteristics of the area. Additionally, simulated solar radiation data will be acquired from the Copernicus Atmosphere Monitoring Service (CAMS) service of Copernicus providing actionable insights into the local ambient conditions of DEMO 6 pilot areas. Finally, in DEMOs at a smaller spatial extent (e.g., DEMO 1 and 4) VHR airborne images and DEMs will further support the project and the evaluation of the stone weirs (DEMO 1.3) and the roundabouts (DEMO 4) efficiency in flood prevention.

4.2.4.2 Integration Plan for Satellite, Airborne/drone-driven data streams

To facilitate the efficient data integration of the EO-based data streams, and additionally assure data standardised accessibility and interoperability, the abovementioned data streams will be integrated into a SpatioTemporal Asset Catalog (STAC) API. The integration procedure is presented in Figure 9. STAC provides a standardised way to expose collections of spatiotemporal data, as all of the records are provided uniformly in JSON formats. Every image will be denoted as an Item, which is an atomic unit and a core part of a general data catalogue, where common EO items are stored. STAC collection will provide additional information about the spatiotemporal data catalogue, defining the spatiotemporal extent, the license (if any), necessary keywords, data providers, and more (radiantearth, 2023).

As presented in Figure 9, two different data sources will be ingested in the EO data platform from ICCS. The first data source mainly refers to the satellite-driven data from the Sentinel-2 mission of the Copernicus programme as well as the Contributing Missions that mainly include VHR data streams of commercial constellations. We foresee extracting both data sources from the Copernicus Data Space and thus storing them in the AWS S3 bucket. Subsequent transformations remain a prerequisite for the interconnection of the cloud-stored scenes to STAC API. A similar data transformation will be followed for the VHR airborne/drone-driven data. However, a specific authenticated client should be deployed, which will allow all the respective demo partners to have access to specific cloud file locations and upload the necessary data. At this point, it should be noted that an important transformation step before ingesting the EO data into the STAC API, is the conversion of the data formats in the Cloud Optimised TIFFs (COGs). In case, DEMO partners cannot facilitate this process, internal transformation procedures will be developed in the EO platform.

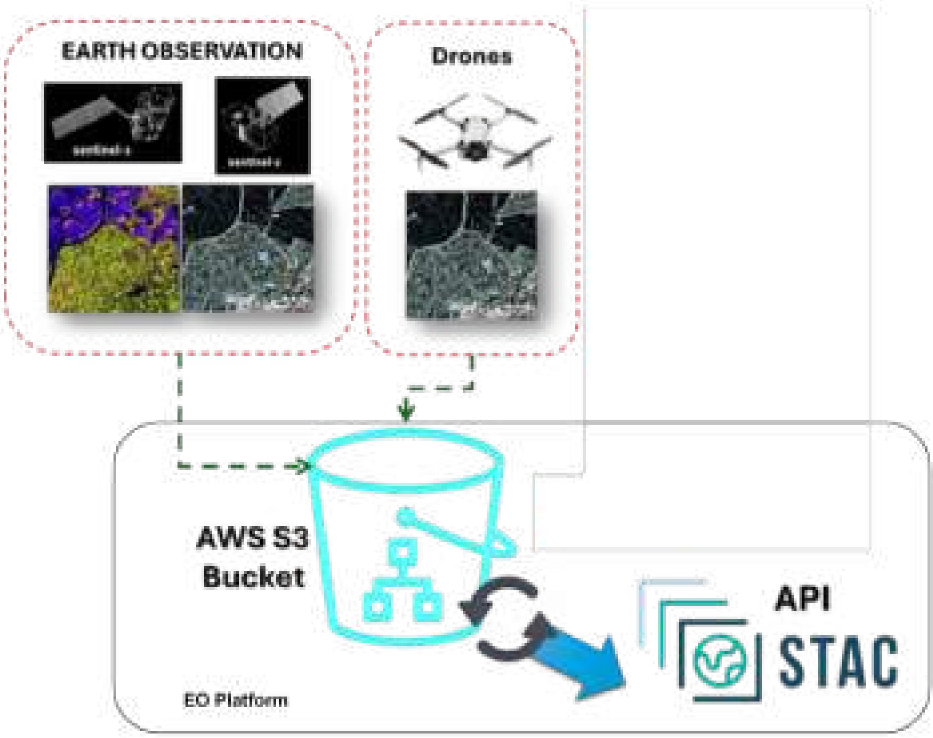


Figure 9: Integration of multisource EO-driven data streams to the MW, after the subsequent storage in the S3 bucket and the harmonisation according to the STAC specification. MW could have access to integrated EO datasets through the STAC API.

5 Unveiling the Data Landscape Playbook findings

5.1 Background

This section employs the DLP methodology to develop a data collection strategy for each DEMO, which will be capable of serving the monitoring process of the NBS impacts, through the defined indicators produced in T4.1 and in detail analysed in D2.2 ("Monitoring Plans"), and to ensure that the spatial and temporal scales of the collected data streams will fulfil the requirements of the WP5 and essentially contribute to the overall impact assessment of the employed NBS solutions from societal, environmental and circular economy viewpoints. The outcome of this process resulted in a total number of 291 datasets (Table 8), with the greatest contributors being DEMOs 1, 3, 5 and 9, respectively.

With respect to the spatiotemporal requirements for the WEFE Nexus models, we should advocate that in order to address this necessity, bilateral meetings were arranged with the WP5 leading partner to review the spatiotemporal details of each reported data asset. Based on this preliminary analysis and since WP5 is at an early stage, it was concluded that the spatial resolution of the data assets reported by the DEMO leaders coincides with the scale of implementation of each sub-demo, ensuring that the data reflects the specific characteristics of the sub-demo sites. However, from WP5's perspective, the key priority is not necessarily achieving a specific spatial resolution but rather ensuring that data is collected at the appropriate monitoring locations within each sub-demo to accurately capture relevant processes and interactions. Regarding temporal resolution, while higher-frequency data is preferred to enhance the accuracy and granularity of the models, WP5 considers the stated monitoring frequencies in the deliverables D2.2 and D4.1 to be adequate for its purposes. The respective partners of WP5 will be responsible for processing and harmonising these datasets and adapting them to address the spatial and temporal resolutions required for assessing various impacts within the WEFE Nexus framework.

Table 8: Number of the reported data streams per DEMO case, which are already collected by existing equipment or past collected campaigns (denoted as existing) or are planned to be collected (denoted as TBC) within the CARDIMED project. DEMOs highlighted in the last right column with Green, belong to the top 20% with the largest number of reported datasets.

DEMOs	Number of data streams		TOTAL per DEMO
	Existing	TBC	
DEMO 1	39	2	41
DEMO 2	1	11	12
DEMO 3	0	47	47
DEMO 4	17	4	21
DEMO 5	48	11	59
DEMO 6	2	3	5
DEMO 7	8	14	22
DEMO 8	8	19	27
DEMO 9	13	44	57
TOTAL ALL	291		

Extensive quantitative and qualitative analysis is performed to examine each DEMO case with respect to the guidelines imposed by the second, third and fourth Plays of the DLP methodology. We reap the benefits of the identified data assets and create nine (9) Data Ecosystems, and therefore address the aspects reported in Table 9. This analysis was facilitated using two web-based software, Datawrapper, and Miro.

Table 9: Definition of the variables that are going to be examined according to the guidelines of DLP, and the type of adopted analysis, denoting as ***QN*** *the Quantitative and* ***QL*** *the Qualitative.*

Play 2: Data Ecosystem Mapping analysed variables		
Data assets per DEMO	Analysis of the data assets that have been reported in each DEMO and perform connections between data and the deployed NBS in each sub-demo case.	QN QL
Data owners/ providers	Analysis of the main data providers, and any existing partnerships between the data owners for the production of a data asset.	QL
Play 3: Data Infrastructure analysed variables		
Data formats	Examine the data formats that have been chosen to store the data assets reported. Divide the data formats according to the data types defined in Chapter 4.2.1.	QN
Data infrastructure	Examine the data interfaces under which the data sources are released in the Middleware of the CARDIMED Platform.	QN
Temporal resolution of data assets	Provides insights with respect to the tendency of each data asset to be frequently updated. To address this aspect and preserve the clarity of this document, we will apply appropriate aggregations (see Chapters 5.2-5.10).	QN
Spatial resolution of data assets	The analysis of the spatial resolution can be solely performed for Earth Observation images, any geospatial data in raster format and digital maps. To perform this analysis, we had to overcome a significant challenge, related to the different definitions of spatial resolution that were provided for the aforementioned products. In particular, the spatial resolution in the EO data streams is always denoted with pixel size, whereas the digital products are usually specified with mapping scales. To combine both types into one common hierarchical categorisation, we adopted the classification proposed by Tobler and	QN

Barbara (1987) and presented in Table 10. Thus, every dataset will be classified from VH up to UL, according to the proposed classification.

Table 10: Association of pixel sizes with mapping scales.

Pixel size category	Pixel size (EO)	Mapping scale (Digital geospatial products)
Very High	<1m-5m	1:1,000 to 1:10,000
High	5m-30m	1:10,000 to 1:250,000
Medium	30m-300m	1:250,000 to 1:1,000,000
Low	>300m	<1:1,000,000
Ultra-Low	>1km	<1:5,000,000

Furthermore, for the point-wise data streams (i.e., in-situ sensors, soil samples, citizen science-driven data, laboratory experiments, etc.), this analysis is inapplicable, since in the majority of the cases are single point locations with specific unchanged coordinates of where the sensors have been installed or where the sample has been taken. Thus, every data asset that belongs to the second case will be denoted as point-wise data.

5.2 Discover DEMO 1 Data Assets

5.2.1 DEMO 1 Data Ecosystem Mapping

DEMO 1 is demonstrated in three Aegean islands (i.e., Lesbos, Mykonos and Sifnos), where all of them are affected by intense water scarcity, long-lasting droughts and intense flash flood events. Coping with these risks, DEMO 1 introduces innovative NBSs across these three Greek islands, denoted as sub-demo cases. More specifically, Sub-DEMO 1.1 will deploy an anaerobic treatment in UASB (Upflow Anaerobic Sludge Blanket), which will enable the filtration and disinfection of the collected water. Two-stage constructed wetlands will purify the wastewater from UASB so as to be used in agroforestry lands. Sludge from wastewater treatment will generate nutrient-rich compost for agroforestry. Electroconductive materials in wetland systems will improve microbial activity and remove pollutants. Finally, vaults and tanks will store and maintain the treated water allowing efficient circular use. Furthermore, sub-DEMO 1.2 (Mykonos Island) will design a rainwater system for reusing the rainwater for agricultural purposes and domestic use. Finally, sub-demo 1.3 in Sifnos Island will attempt to construct 120 traditional stone weirs strategically placed across two main streams to reduce the water runoff and thus mitigate the flash flood events. This NBS solution will also redistribute the collected water in the agricultural areas, enriching the aquifer and improving the local ecosystem.

To precisely evaluate the impact of the employed resilient solutions in DEMO 1 and provide measurable findings for the suggested NBS KPI indicators for the DEMO, all three sub-demos will introduce a plethora of data streams spanning different data acquisition systems. Figure 10 illustrates the collected data streams for the three demo cases and the main data providers. A subsequent division is performed categorising the data providers in three different levels (e.g., consortium members, members of a governmental agency and members of an EU organisation).

The main data provider for sub-demo 1.1 is the National Technical University of Athens (NTUA) produces a comprehensive suite of data streams resulting from the in-situ installation of sensing devices and laboratory experiments. Regarding the first category water quality sensors are foreseen to monitor the impacts of water treatment, acquiring flow pressure, soil humidity and temperature data. Additional meteorological variables will be collected such as ambient temperature, wind speed and direction and precipitation. Extensive samples will assess microbiological and chemical parameters as a result of the reclamation process. These include dissolved oxygen (DO), oxidation-reduction potential (ORD), chemical oxygen demand (COD), biological oxygen demand (BOD5), ammonium (NH4+), nitrates (NO3-), total nitrogen (TN), orthophosphate (PO4-P), total phosphorus (TP) and sulphates (SO4). Additionally, explicit laboratory analysis will be performed producing data related to biogas production and the microorganisms such as Escherichia coli (E. coli) that are generated due to anaerobic composting. Finally, the positive impact on the cultivation will be measured with the harvested yield, the fertilizer and water parcel's needs and the cultivated plant species.

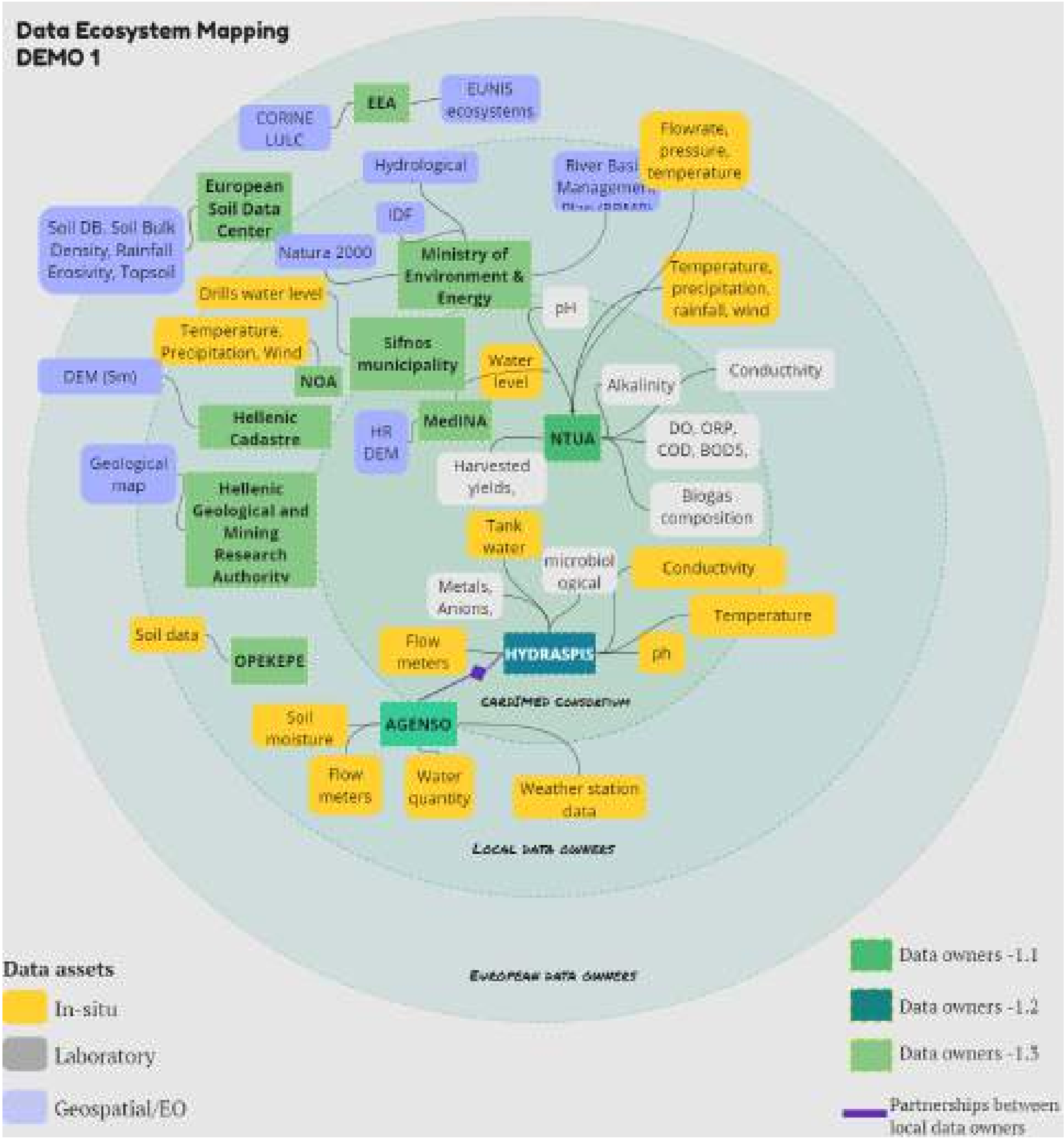


Figure 10: Data Ecosystem Mapping of DEMO 1, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers.

In the second sub-demo case, Hydrapsis is responsible for the employment of both in-situ and laboratory analysis to evaluate the preservation of rainwater. Urban water quality assessments will be applied by collecting conductivity, pH and water temperature data, while a specific water level sensor will be responsible for measuring the water level in tanks. Laboratory analysis will be applied to identify metals, anions and cations in the retained water. A noteworthy partnership exists between Hydrapsis and Agenso to collect soil moisture, water quantity and water flowrate measurements, as well as meteorological observations (i.e., ambient temperature, relative humidity, rainfall, wind speed and direction, and atmospheric pressure), evaluating the water quantity that is about to be stored in the tanks.

Finally, sub-demo case 1.3 is characterised by the majority of the data providers spanning three different levels (i.e., consortium, local and EU). MedINA aims to produce high-resolution (HR) DEM from drone campaigns and to pre-install water level sensors at selected farmers' wells and specific locations along the two streams of intervention. A specific geospatial dataset is already available from the municipality of Sifnos. National data providers such as the National Observatory of Athens (NOA), the Greek Payment Authority of Common Agricultural Policy (CAP) Aid Schemes (OPEKEPE), the Hellenic Cadastre, the Hellenic Geological and Mining Research Authority and the Ministry of Energy will contribute with complementary in-situ and EO data, serving an essential role in risk assessment and planning. At the EU level, the EEA and the European Soil Data Center have already offered a greater spatial scale data stream to analyse the impacts of the applied NBS solution, by the hydraulic Intensity-duration-frequency curve (IDF) modelling analysis.

5.2.2 DEMO 1 Data Infrastructure

Moving to the technological infrastructure of DEMO 1, Figure 11 highlights the dominance of CSV (26 reported cases in total covering both the existing and the "to be collected datasets"), a file format which will be used for the datasets from the laboratory analysis and non-IoT in-situ sensor infrastructure. Microsoft Excel format is the second option serving the same applicability (reported 16 times in total). Additional preferred data formats are the Tag Image File Format (TIFF)/GeoTIFF (identified in 6 existing data assets and 1 TBC), for raster-based data resulting from EO datasets or HR geospatial products. The aforementioned is further complemented with ESRI shapefiles and JavaScript Object Notation (JSON)/GeoJSON data (3 in total cases for each file format) for vector-based geospatial data, which are solely adopted by the EU data providers (i.e., EEA and European Soil Data Center). Finally, less dominant choices are Portable Document Format (PDF) and text-based (ASCII/TXT) files, with the first intended to be replaced as the project evolves.

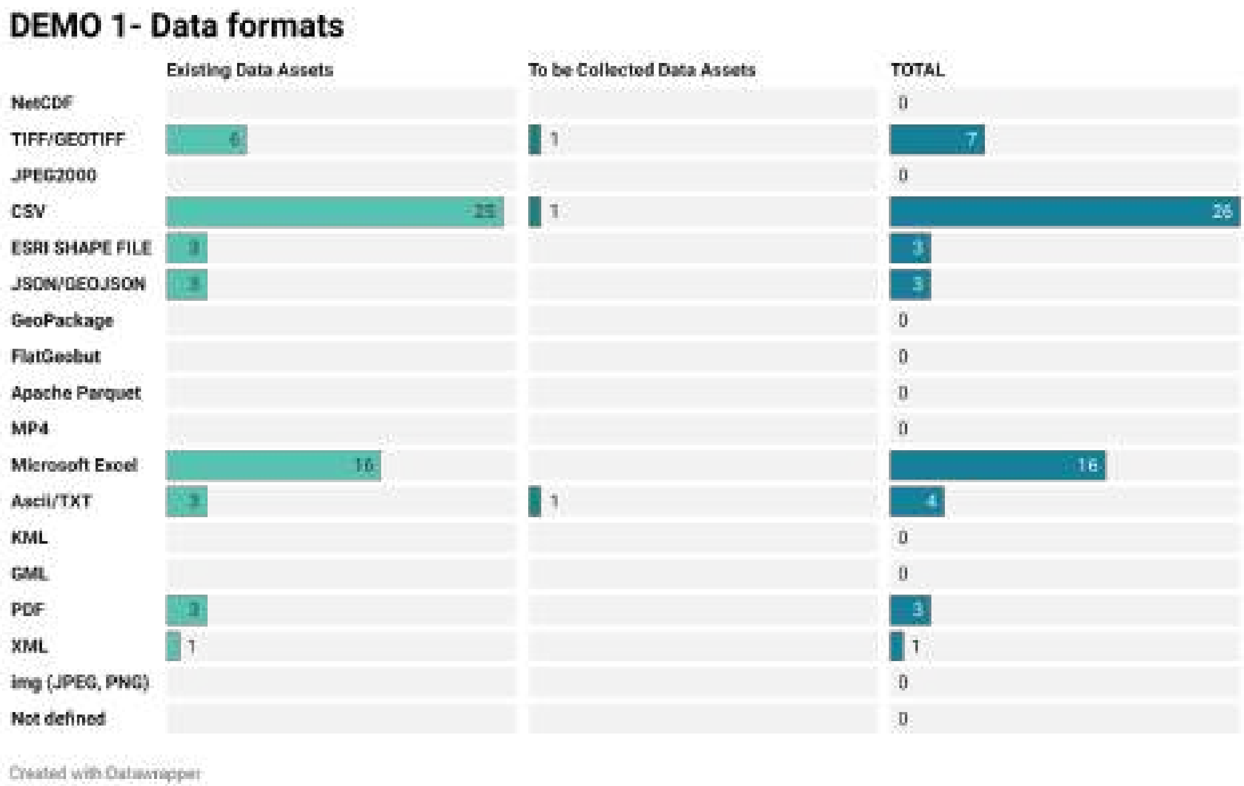


Figure 11: Data formats that have been chosen by DEMO 1 for storing the collected data.

Considering the accessibility interfaces (Figure 12), data portals cover the majority of the reported datasets (14 in total for the existing datasets). On some occasions, OGC Web Services (WMS and WFS) are provided as a complementary solution. Nevertheless, this solution expresses datasets provided by external organisations, which have not been declared as of significant importance. The majority of the collected data streams are planned to be transmitted through the Message Queuing Telemetry Transport (MQTT) protocol into the respective broker of MW, which will run on top of the Supervisory Control and Data Acquisition (SCADA) industrial interface. The latest could be considered as the dominant infrastructure for sub-demo cases 1.1 and 1.2 (see further details in Chapter 6.1). AGENSO has established a RESTful Application Program Interface (API) for having the data accessible. Furthermore, the EO-data platform of ICCS will be used to handle the reported EO-based data streams of DEMO 1. Finally, a centralised file server will be employed by the MW, allowing the demo partners to store the generated data streams in cases where a Machine-to-Machine (M2M) infrastructure is not available. Demo 1 will leverage the file server and mainly report the results from the laboratory experiments.

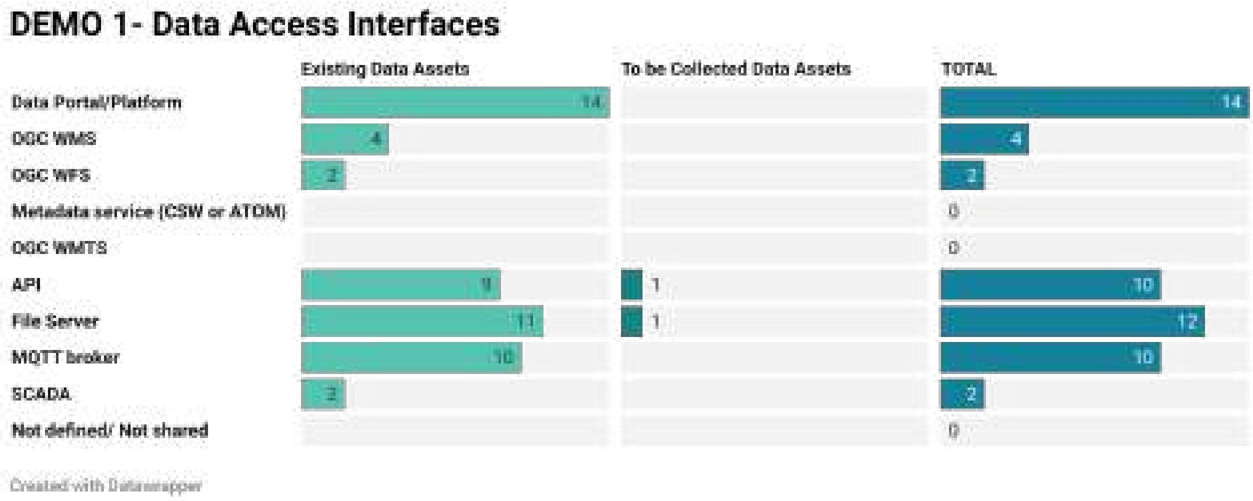


Figure 12: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 1 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6).

Furthermore, with respect to the temporal resolution of the DEMO 1 reported datasets of DEMO 1 (Figure 13), the highest percentage of collected datasets (15 in total) will be derived from in-situ sensing monitors and thus are planned to continuously provide us with a near-real-time (NRT) update regarding the NBS treatments. Data records, which reveal a weekly (2 in total) or monthly (9 in total) tendency of being produced normally express the datasets from the laboratory analysis, which is a long-lasting procedure of approximately 1-2 weeks. Irregular or not updated/defined cases are a notable percentage of the existing data assets, and we presume that predominantly express historical data collections. Finally, the two data records with a temporal resolution of 5 years and higher are only related to the CORINE LULC dataset, which is planned to be updated every 6 years. As a whole, we should declare a heavy reliance on DEMO 1 on high-frequency data rates, reflecting the requirement of a dynamic and continuously monitoring data ecosystem. Eventually, as it was described earlier, the majority of the deployed data collection systems have resulted from the in-situ networks or the laboratory experiments. Thus, almost all the data streams will be point-wise data, with only two exemptions that describe the VHR DEM datasets and the EU-generated products. Therefore, further details on the data sampling strategy are provided in D2.2.

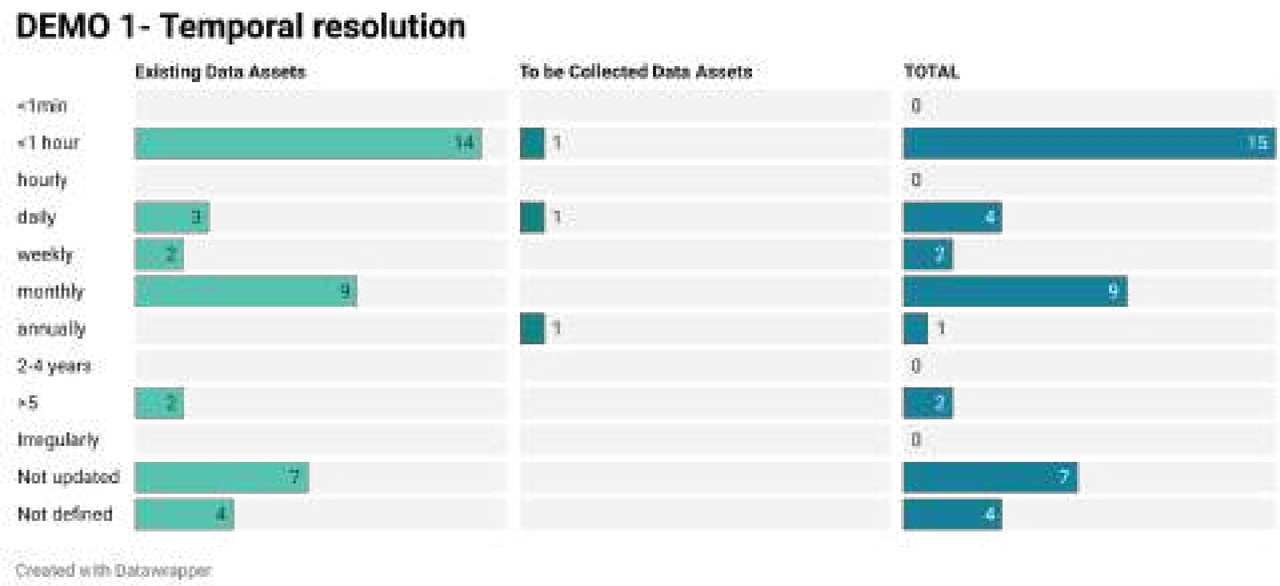


Figure 13: Illustration of the temporal resolution that the released data assets will have in DEMO 1.

Figure 14: Illustration of the spatial resolution that the released data assets will have in DEMO 1.

5.3 Discover DEMO2 Data Assets

5.3.1 DEMO 2 Data Ecosystem Mapping

DEMO 2 will attempt to deploy a Driven Industrial Water Symbiosis System (DDIWSS) to optimize and therefore manage the use of different water sources, the inspection of the existing pipe network and facilitate better treatment of rainwater harvesting, grid/pump water, recycled water and wastewater. DDIWSS will incorporate two NBS solutions, i.e., a biofiltration unit and a bioswale to reduce and filter the rainwater runoff, allowing the subsequent storage and reuse of the urban and rainwater. With the existence of a hybrid digital twin, this pilot will optimise the water allocation in NRT and reduce the water footprint in the whole facility. To assess the impact of the aforementioned NBS deployment, a plethora of data streams either from existing in-situ networks or for laboratory analysis will be collected (Figure 15).

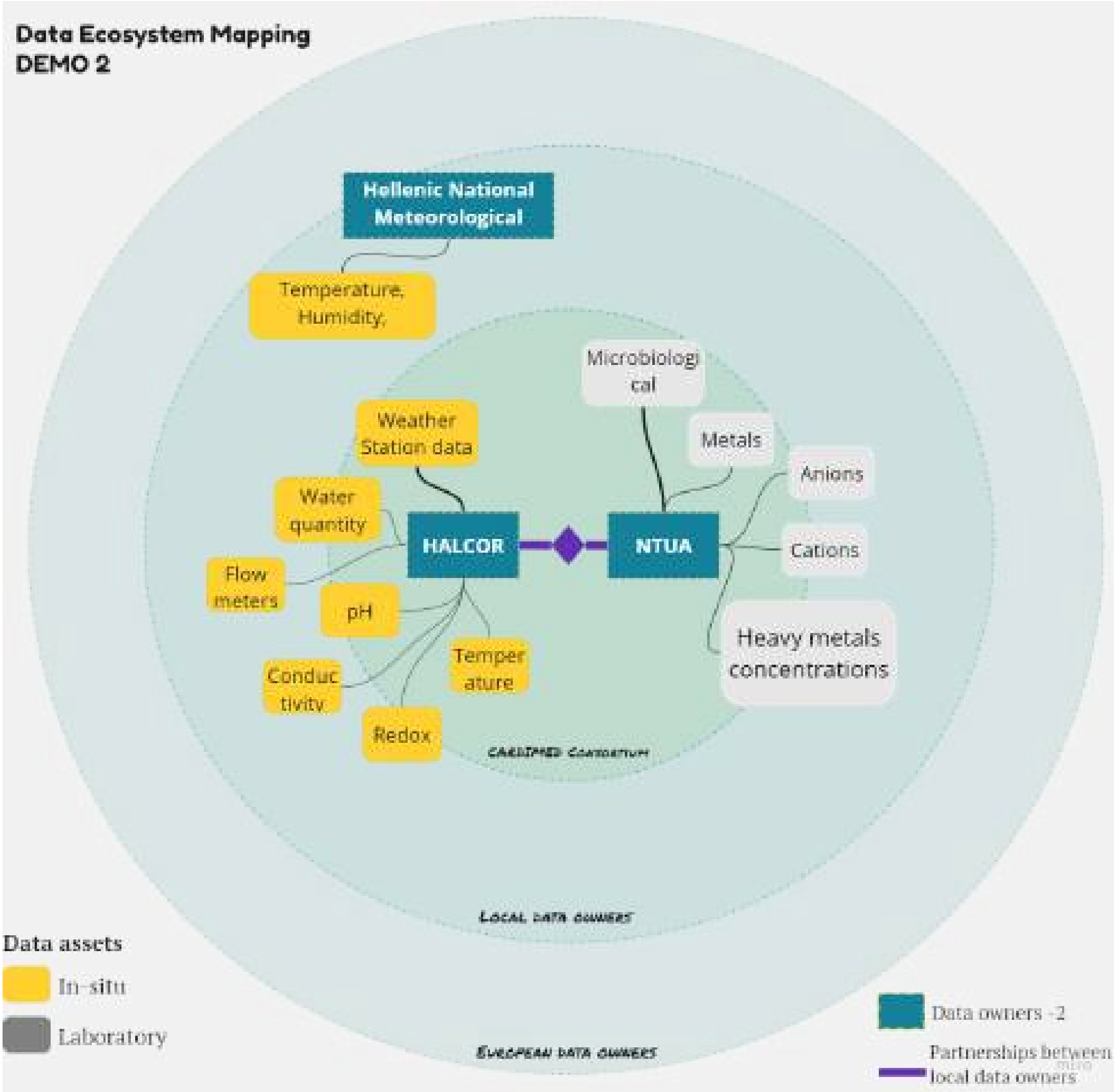


Figure 15: Data Ecosystem Mapping of DEMO 2, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers.

DEMO 2 reveals a data ecosystem of significant importance, which mainly resulted from an extensive network of in-situ sensing devices and laboratory experiments. With respect to the first data collectors, HALCOR aims to gather through a weather static station continuous data streams related to ambient temperature, relative humidity, wind speed and direction. Additionally, water quality and quantity sensors are planned to be installed in the locations where the reclaimed water will be cleaned and stored, providing data-driven insights on the water level, the flow rates and several chemical parameters indicating the water quality i.e., pH levels, conductivity and redox potential. The last variable measures the tendency of a chemical species to acquire electrons from or lose electrons. Furthermore, water data samples will be acquired by the NTUA and thus perform laboratory analysis to determine any microbial activity and the presence of potential contaminants. Additional chemical parameters will be investigated, referring to the anions and cations (ionic species in the water), metals that indicate the existence of mineral pollutants in the water and heavy metal concentrations, ensuring compliance with the environmental and Water ISO regulations. The Hellenic National Meteorological Service will provide the ambient meteorological profile of the general area. However, there is an intention to replace this weather station with an in-house infrastructure installed by ReonHydor (REHY) to achieve better spatial accuracy on the local conditions and water network modelling. At this point, it should be stated that additional data streams are expected in the long run of this DEMO, as the REHY, the Hydraspis or the Region of Central Greece (PSTE) haven't reported any during the data collection process.

5.3.2 DEMO 2 Data Infrastructure

As described in Chapter 5.1 a pivotal step of the DLP and Task 4.2 is to investigate the file storage formats and all the prerequisites that will permit these data streams to be effortlessly ingested in the MW platform of CARDIMED. With respect to the adopted storage formats (Figure 16), DEMO 2 will establish CSV and JSON/GeoJSON formats at the highest percentage (reported 11 and 7 times in total). The first file format will be used for the laboratory data, while JSON will be used for the in-situ sensing observations. Complementary, Extensible Markup Language (XML) was mentioned 7 times, but at this point, but mainly concerns the metadata definition. Microsoft Excel was defined 4 times as an alternative for the laboratory data. Finally, a single data source will be stored in TXT format, and this mainly describes the meteorological records from the Hellenic Meteorological Agency.

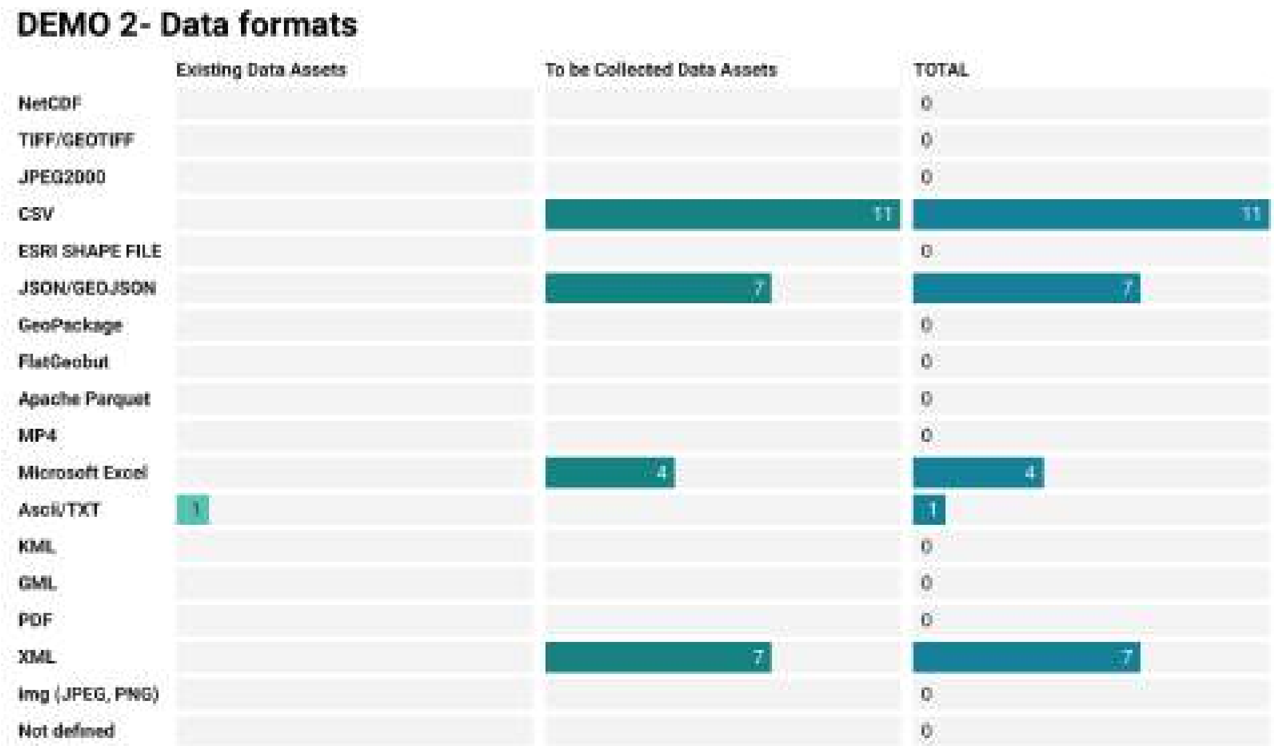


Figure 16: Data formats that have been chosen by DEMO 2 for storing the collected data.

Continuing with the data access interfaces (Figure 17), three predominant transmission technologies will be used, with one to serve the in-situ network and the other the laboratory data. In particular, SCADA and MQTT brokers will be exploited as interconnected components. SCADA is usually explored for real-time monitoring and communication with the in-situ network and data exchange. Open Platform Communications Unified Architecture (OPC-UA) usually operates within the SCADA system and facilitates secured and standardised M2M communication and data exchange. To successfully perform the data exchange between the SCADA system and the MW of the CARDIMED platform, an MQTT client is foreseen to be deployed, allowing the in-situ data transmission to the MW MQTT broker. Further details are provided in Chapter 6.2.1. All the laboratory data are expected to be manually uploaded to the centralised file server. Finally, the fact that the weather station data of the Hellenic National Meteorology Agency is expected to be manually extracted and uploaded to the file server.

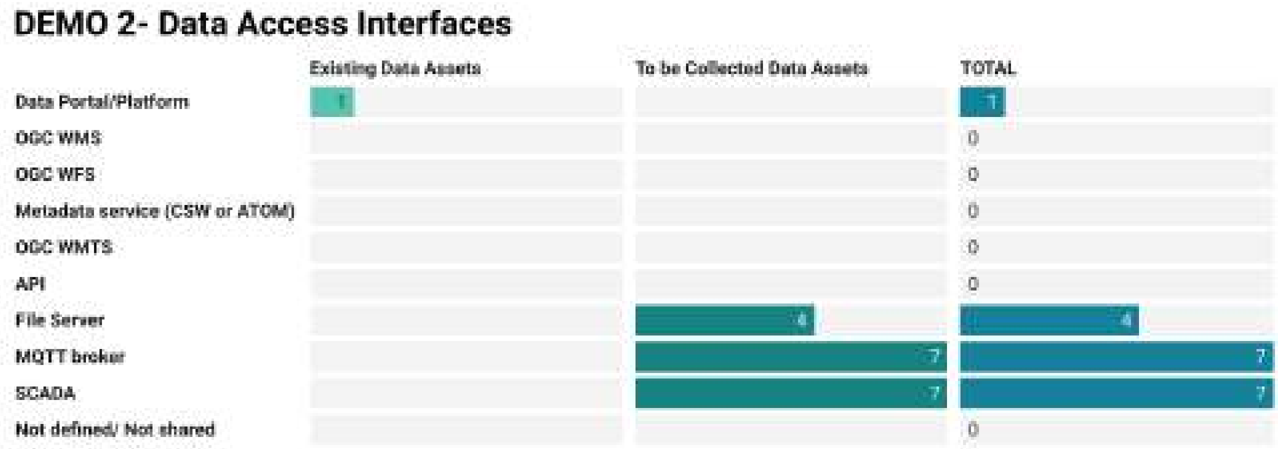


Figure 17: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 2 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6).

In terms of temporal resolution (Figure 18**Error! Reference source not found.**), a significant proportion of data streams are intended to be updated in less than one hour. This category expresses mostly the in-situ network operations. On the other hand, the laboratory experiments (1 in existing data assets and 4 in the TBC data) will be updated twice a month (assigned in the monthly category). Finally, a single case is under investigation, referring to the flowmeters data acquisition. Moreover, the majority of reported datasets express point-wise deployments and thus have been classified as point data, where a spatial resolution analysis cannot be applied (Figure 19).

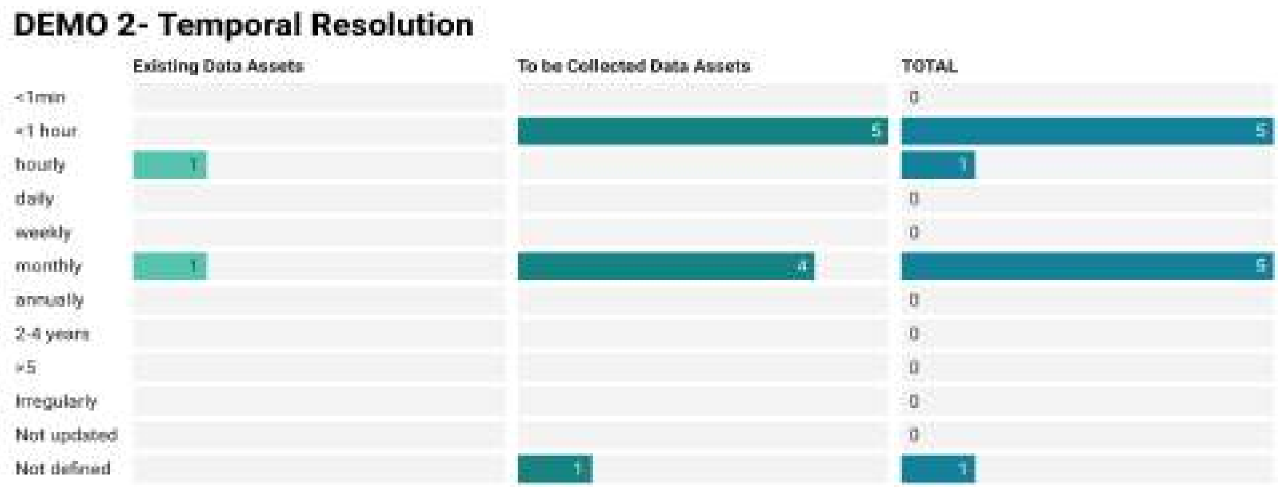


Figure 18: Illustration of the temporal resolution that the released data assets will have in DEMO 2.

Figure 19: Illustration of the spatial resolution that the released data assets will have in DEMO 2.

5.4 Discover DEMO3 Data Assets

5.4.1 DEMO 3 Data Ecosystem Mapping

DEMO 3 will deploy five NBS solutions in Alghero (Italy) related to wastewater management, as parts of the San Marco Wastewater Treatment Plant (WWTP). More specifically, the tertiary and quaternary Treatment will reduce the water pollutants and contaminants. Microalgae cultivation will naturally infiltrate the wastewater through nutrient absorption. Free Surface Wetland and Riparian Buffer infiltration systems will remove the water pollutants from the surface water and thus contribute to the improvement of the water quality and ecosystem restoration. Crop rotation treatment will follow an iterative cultivation approach and thus will be rotated and planted sequentially throughout the year. The rotated crops will be continuously irrigated from the reclaimed water. Finally, an aquaculture facility will enhance the nutrient lifecycle of water and increase water quality.

Targeting these impactful objectives, DEMO 3 foresees generating a data ecosystem of significant interest, extending it solely to the internal consortium partners. In particular, the Universita Politecnica Delle Marche (UNIVPM) and the Alma Mater Studiorum - Universita Di Bologna (UNIBO) have dictated as the only data providers of this demo case (Figure 20), covering both in-situ and ex-situ data acquisitions. Analysing the in-situ data collections, water quality sensing monitors are planned to be installed in the various parts of the WWTP, providing critical observations referring to the water treatment, the microalgae cultivations, as well as the free surface wetland and the riparian buffer. Probe instruments will be installed and collect data streams of dissolved oxygen, electrical conductivity, pH, temperature, groundwater level, and flow rates. Subsequently, Photosynthetically Active Radiation (PAR) probes will measure the intensity of light in the 400-700nm to monitor the plant photosynthesis in the microalgae cultivations and the fluorescence and absorbance reflecting the tertiary and quaternary treatment, and in overall water quality improvement.

With respect to the rotated parcels, a specific soil sampling strategy has been defined in D2.2, and thus soil samples will be gathered at least twice a year, which will be further analysed in highly experienced laboratories. Chemical and biological substances will be estimated such as NH_4, NO_2, NO_3, Soil Organic Carbon (SOC), bulk density, carbon stock, particle size fractions (clay, silt, sand, etc.) and soil chemical attributes (pH, Organic Carbon, Nitrogen (N), Phosphorus (P) and Potassium (K), Cation Exchange Capacity, Heavy Metals and Contaminants). Additional laboratory analysis will be performed to assess the water quality in the aquaculture environments, the water treatment system and the microalgae cultivations. Indicative examples of the produced datasets include salinity, chemical and biochemical oxygen demand (COD-BOC), total suspended solids (TSS), Ntot, Ptot, E. coli, legionella (genus of bacteria commonly found in freshwater), nematode (roundworm type found in water and soil), salmonella (a genus of bacteria that can cause foodborne illness) and the greenhouse gases (GHG) emissions. Finally, additional data will be collected and cover video cameras that will attempt to capture the fish presence, self-feeders, and harvester machines indicating the crop cultivation processes. Concerning the rotated crops, the soil resilience index (SRI) will be calculated, indicating the soil's ability to provide services and recover from stress.

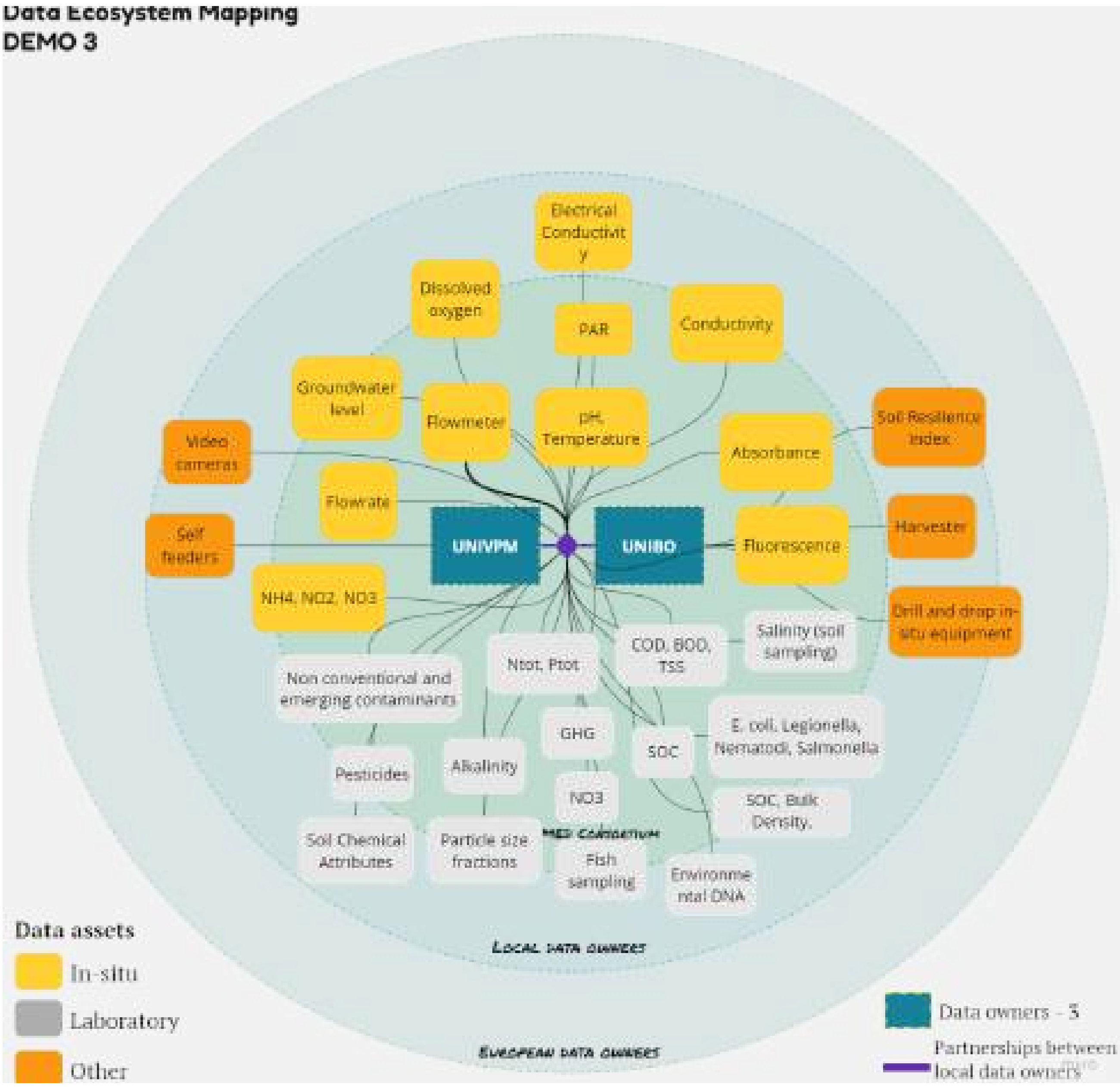


Figure 20: Data Ecosystem Mapping of DEMO 3, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers.

5.4.2 DEMO 3 Data Infrastructure

Considering the mostly chosen file formats (Figure 21), Microsoft Excel spreadsheets will be used by the data providers of DEMO 3 for both the in-situ and the laboratory data streams. We shall declare that this solution might seem suitable for the laboratory data as the data collection frequency will be on a monthly basis. Nevertheless, for in-situ monitors, we presume that the only possible way to maintain this file format is to first store offline the in-situ monitors on SD cards or local storage facilities, combine the information gathered from several days and thus provide these aggregated datasets spanning many days.

All the aforementioned indicates that this specific demo will not adopt a real-time or near-real-time data collection strategy, as it cannot be supported either by the chosen infrastructure (Figure 22) or the chosen file format. Finally, only one data stream is differentiated from the general tendency, which is the videos collected in MP4 format, but demo leaders reported that these data streams will only be used for internal purposes.

Two undefined cases indicate not explicitly the absence of the file format but equipment which is not meant to generate a data source. These refer to the harvester and the soil drilling equipment.

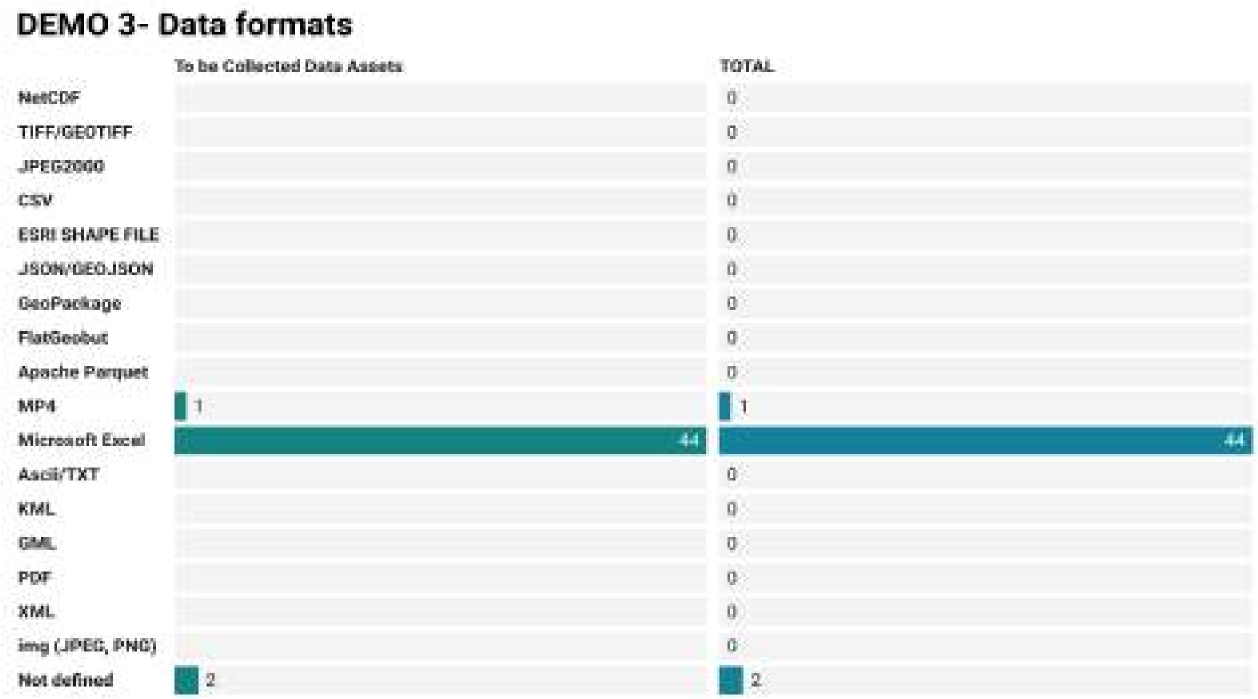


Figure 21: Data formats that have been chosen by DEMO 3 for storing the collected data.

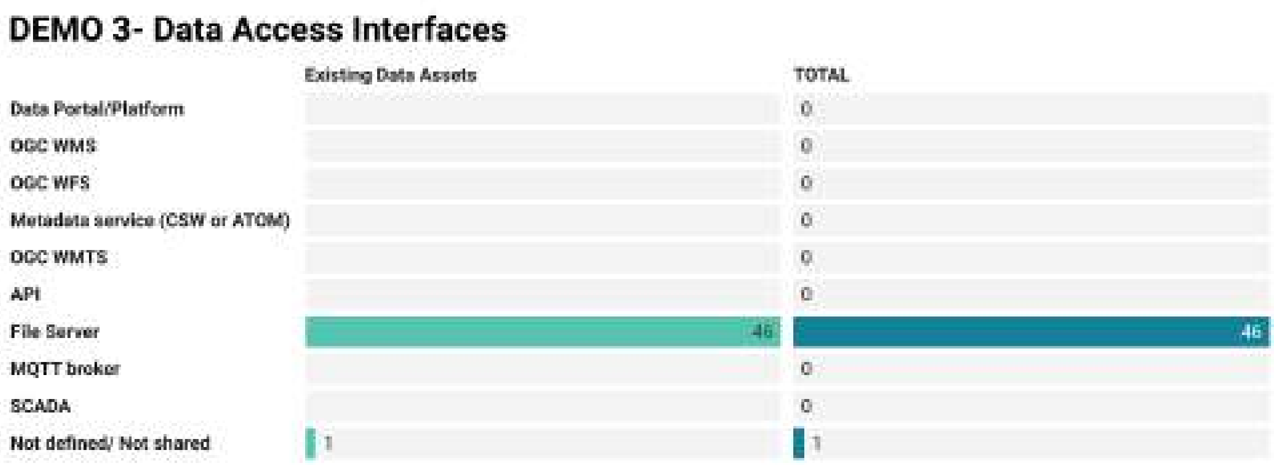


Figure 22: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 3 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6).

With respect to the temporal resolution (Figure 23) the majority of the reported datasets (19 reported cases) are planned to be collected on a weekly basis, and this mostly describes the soil sampling campaigns as well as the respective laboratory experiments. Another notable frequency of data production of less than an hour (10 datasets) refers to the in-situ sensing monitors that transmit seamlessly through the proprietary Hanna and Hach protocols the collected observations. On six (6) occasions, the reported data streams will be daily transmitted. For these cases, the observations will be initially stored in SD cards or USB and then uploaded to the centralised cloud file server, prohibiting any continuous data collection.

In contrast, some data collection is planned on an annual basis (7 reported cases) as they are subjected to the yield monitoring phases of the rotated crops. A small subset of datasets falls under the not defined category (4 cases in total) showcasing a minor necessity to define at this moment the frequency of data collection. Overall, the data collection strategy for this specific demo case solely includes in-situ sensing data acquisitions, and thus any further analysis with respect to the spatial resolution seems less prominent at this stage of the project. The results of our investigation process are illustrated in Figure 24.

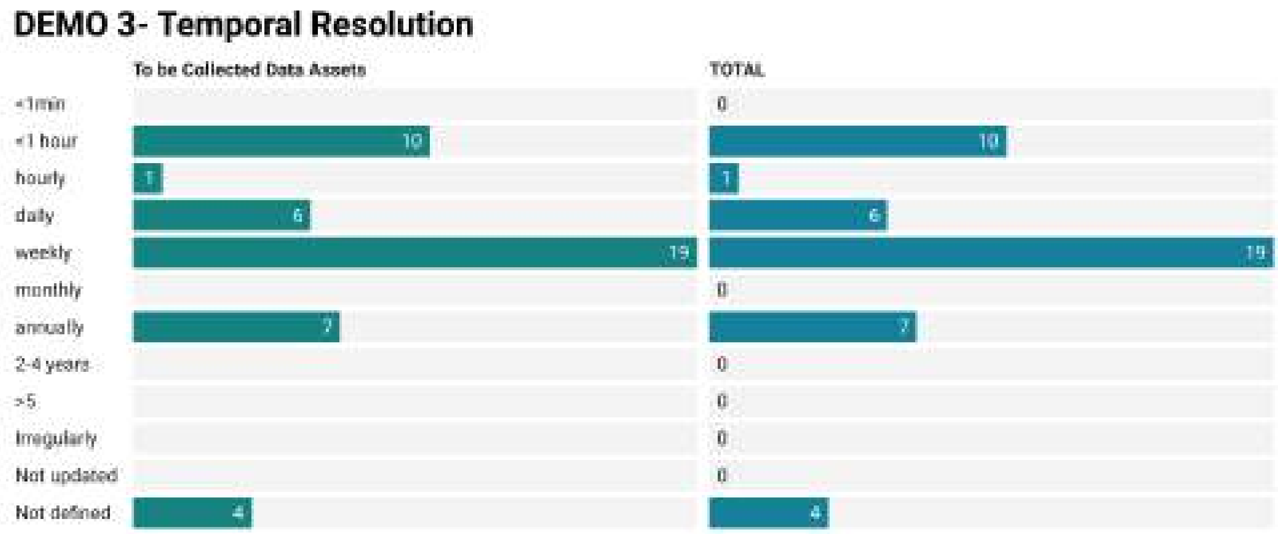


Figure 23: Illustration of the tendency of DEMO 3 to maintain the data production through the pre-determined time intervals.

Figure 24: Illustration of the spatial resolution that the released data assets will have in DEMO 3.

5.5 Discover DEMO4 Data Assets

5.5.1 DEMO 4 Data Ecosystem Mapping

The main objective of the fourth DEMO case is to introduce NBS, capable enough to address urban flood risk and water scarcity. In the first sub-demo case, the general objective is to mitigate the extreme damages generated by the flash flood events and thus bioretention cells employed in Catania to reduce the sudden rainwater runoff. Additional treatments will attempt to improve the water quality by filtering the pollutants, which eventually will be harvested in specialised tanks for storing and used for emergent irrigation purposes. Furthermore, the second sub-demo case, denoted as the "Green Walls of Ferla" is employed at a primary school in the Ferla region and mainly involves the installation of a pot-based green facade on three sides of the building, which is designed to treat greywater from washbasins.

In these two sub-demo cases, an actionable data volume will be gathered to measure the effectiveness of the deployed NBS solutions (Figure 25). The first sub-demo case involves collaboration with both internal and external local partners, with only one data record (i.e., CORINE LULC) to be provided by an EU organisation, the European Environmental Agency (EEA). Furthermore, the University of Catania (UNICT) is responsible for gathering and analysing data sources from in-situ and laboratory experiments (i.e., water flow, volume, moisture or level) for the sub-demo 1 case. Additional variables such as electrical conductivity, pH levels, TSS, COD, Ntot, and Ptot will be produced. An in-situ weather station is expected to be installed and collect continuous observations of ambient temperature, rainfall, solar radiation, wind speed and direction, pressure and relative humidity. The same infrastructure already exists and is owned by the Sicilian Agrometeorological Information Service (SIAS) and is intended to be used as an alternative.

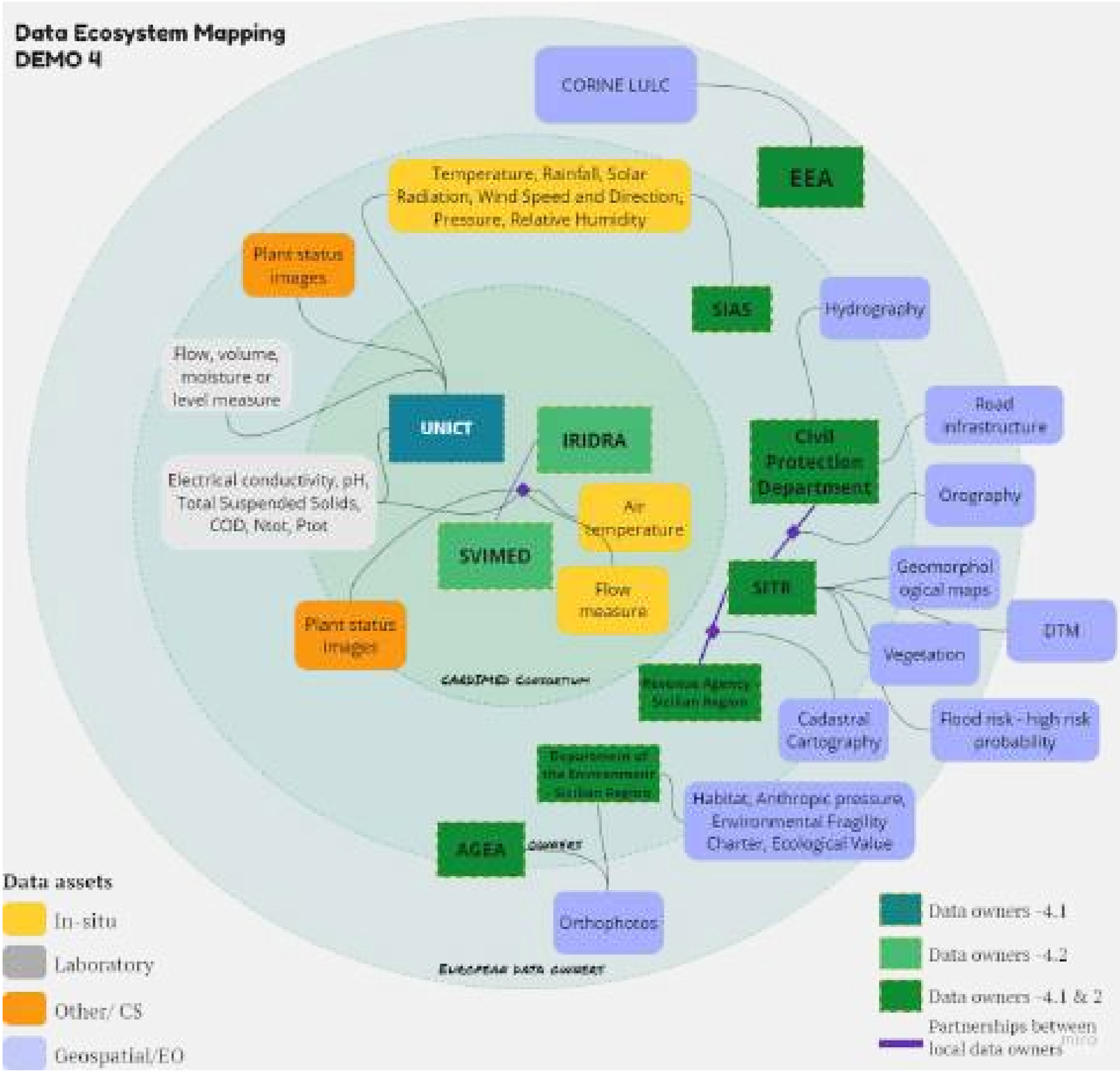


Figure 25: Data Ecosystem Mapping of DEMO 4, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers.

Continuing, a joined partnership between IRIDRA and SVIMED partners will serve the data demands of sub-demo 4.1, measuring the flow rates, water levels and air temperature. Complementary images will be collected as visual proofs of the good state of plants' health, growing in both the rain garden in the roundabout of Catania (sub-demo 4.1) and the green walls of Ferla (sub-demo 4.2). Nevertheless, it is not certain if the images will be integrated into the MW platform or will be solely exploited for internal purposes. Furthermore, as illustrated in Figure 25, both sub-demo cases aim to explore a plethora of geospatial datasets produced by local organisations. These refer to digital terrain model (DTM), geomorphological and vegetation maps, flood risk assessment geospatial layers from the Regional Territorial Information System (SITR), VHR orthophotos produced by two organisations (i.e., Advanced Geological Environmental Assistance (AGEA) and Department of Environment in the Sicilian region), hydrography, road infrastructure and orography digitalised layers from civil protection department. All the aforementioned layers will significantly contribute to the vulnerability assessment in flood risk and water scarcity of the surrounding areas.

5.5.2 DEMO 4 Data Infrastructure

Analysing each data source so as to examine the mostly chosen data formats (Figure 26), demo 4 seems to adopt a diverse set of file storage types for geospatial, tabular and image-based data streams. Starting with the image-based data, TIFF/GeoTIFF has been selected in 6 existing cases to store data related to the orthophotos, DTM and CORINE LULC. The meteorological observations will be distributed in TXT format, while the availability of the road infrastructure will be provided in JPEG. On the other hand, citizen science image data of plant health status will be again collected in JPEG format from mobile phones. Furthermore, the ESRI shapefile data format, which has been reported 5 times in total, predominantly describes the geospatial data described in Chapter 5.5.1. In three reported cases, JSON format will be adopted by the agronic third-party company, in which the collected sensor data will be transmitted to the backend of the agronic web platform and will be accessible through an API. Finally, 3 additional tabular cases exist (1 CSV and 2 Microsoft Excel) and they will be solely adopted for the laboratory data.

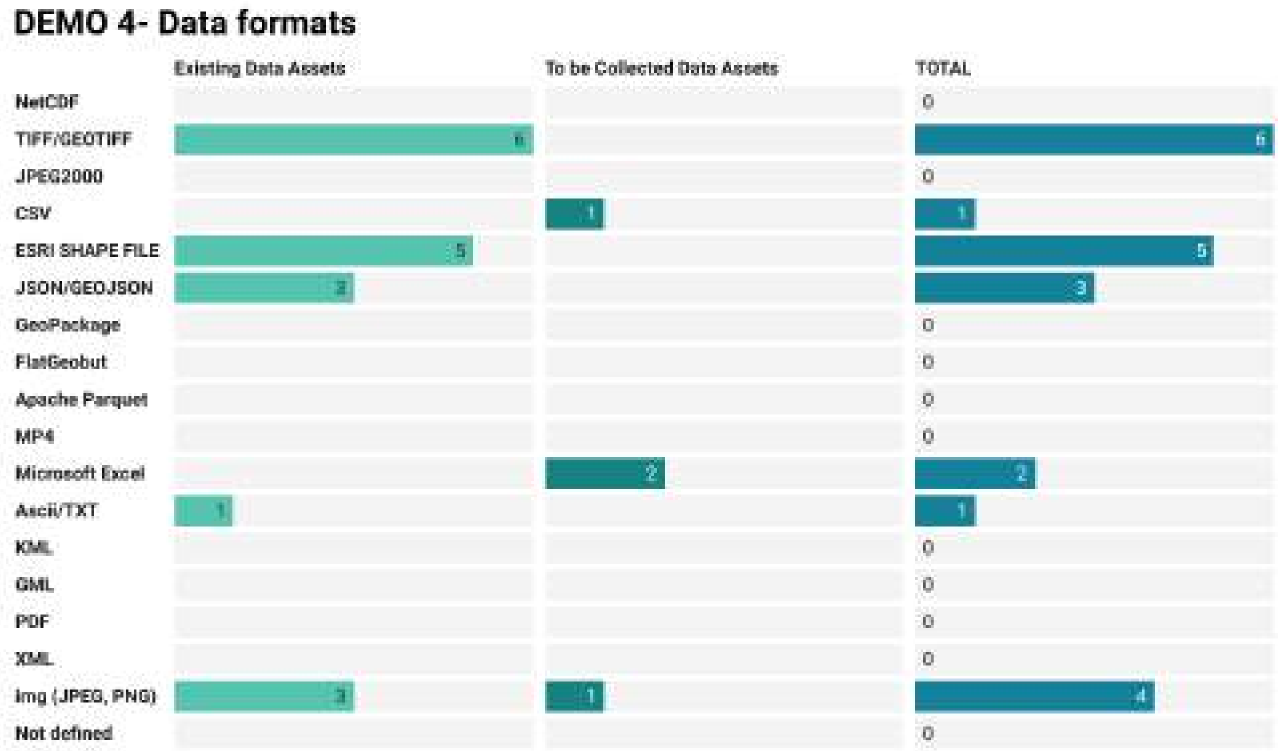


Figure 26: Data formats that have been chosen by DEMO 4 for storing the collected data.

The data access interfaces in DEMO 4 (Figure 27) demonstrate a strong reliance on data portals (reported 14 times in total) that share the geospatial datasets. OGC-compliant WMS services complement nine of the aforementioned cases, enabling the dynamic integration and visualisation of the collected data assets. OGC-WMTS and metadata services like CSW or ATOM opted for structured access in imagery-driven data streams. RESTful APIs (5 times in total) and the centralised file server (1 in existing data assets and 4 reported for the

TBC data) of the MW platform will mostly facilitate the data transmission and accessibility of the in-situ data and the laboratory experiments.

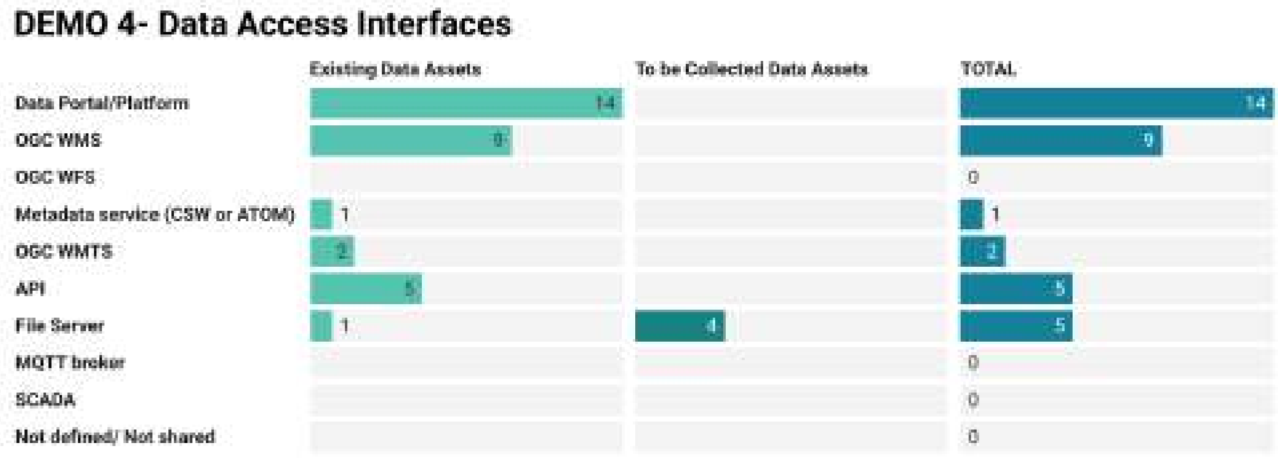


Figure 27: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 4 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6).

In terms of the intention to maintain such valuable data sources, Figure 28 illustrates that several variables will be continuously produced. Nevertheless, this characterises only a small segment of data streams as the majority of them either are not defined, or the datasets are updated irregularly or not at all. Additionally, we are also missing the specifications of the temporal resolution for future data collection campaigns, something that should be defined as it has a critical impact on both the evaluation of the NBS KPIs and the deployment of the WEFE Nexus models.

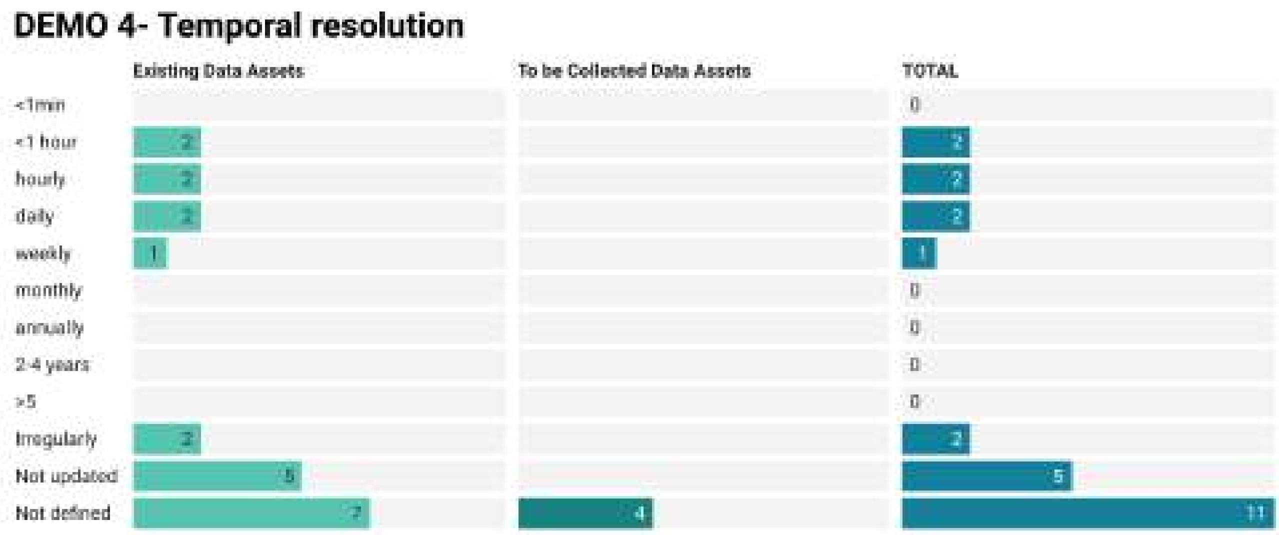


Figure 28: Illustration of the temporal resolution that the released data assets will have in DEMO 4.

Finally, regarding the spatial resolution requirements, it appears that this specific demo case is characterised by both rasterised (10 datasets) and point-wise data assets (6 cases), with the majority of them belonging to the first category (Figure 29). Overall, all the rasterised products fall in the category of VHR products (9 reported data in total) with only one to consider the existence of datasets at a coarse resolution. This is mainly associated with the CORINE LULC products which according to the descriptions given by the DEMO leaders the mapping scale of this product is 1:10,000.

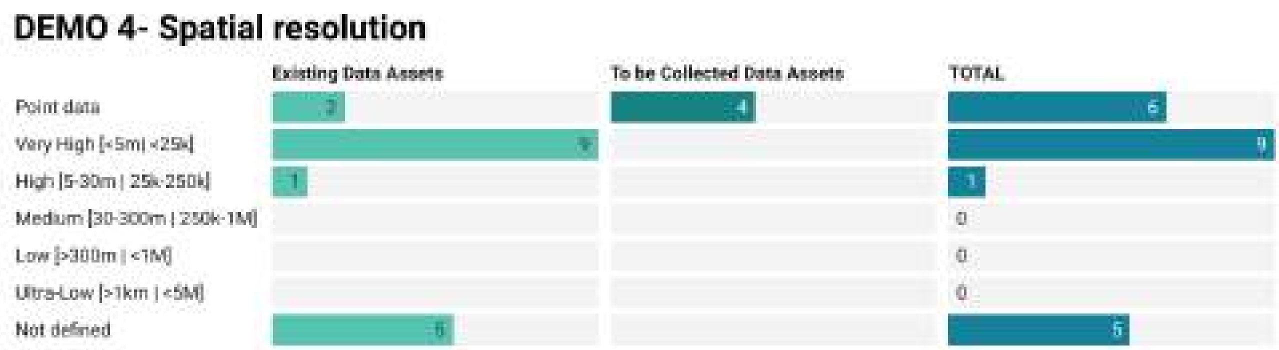


Figure 29: Illustration of the spatial resolution that the released data assets will have in DEMO 4.

5.6 Discover DEMO5 Data Assets

5.6.1 DEMO 5 Data Ecosystem Mapping

DEMO 5 will attempt to launch two sub-demo deployments in the Provence-Alpes-Côte d'Azur (PACA) region in France in order to mitigate the extreme and long-lasting heat waves and soil degradation. For the evaluation of the benefits of the employed NBSs in the two sub-demo cases, key data owners spanning from inside the consortium up to the EU level will synthesise the data ecosystem mapping, as illustrated in Figure 30.

Starting with the first sub-demo case in Saint-Jerome, local data owners like the European Center Research and Teaching in Geosciences De L'envi (CEREGE) aim to contribute to soil and groundwater data collection through and provide in-situ observations on soil layer, carbon storage, soil permeability, water infiltration, groundwater temperature, groundwater height, and electrical conductivity. Additional observations include variables such as electrical resistivity tomography (ERT) and magnetism, along with soil pollutants and carbon storage analysis, which resulted from a chemical process.

Furthermore, for the second sub-demo case, the University Institute of Industrial Thermal Systems (IUSTI) is committed to collecting meteorological and climatic data with the deployment of a weather station. Variables of the major interest are temperature, humidity, precipitation, wind speed and direction, atmospheric pressure, and global sunshine. The aforementioned data streams will be enhanced by the low-cost citizen science indoor and outdoor weather sensors of the Netatmo, spread throughout the region. AtmoSub aims to provide data on temperature, air quality and precipitation, both collected from static in-situ sensors as part of the Nature for City and the DIAMS projects and from 13 mobile microsensors. Subsequently, GEOTEC and CEREGE will supply in-situ soil health and water quality observations, including soil pollutants, water infiltration, soil nature Groundwater temperature, electrical conductivity and height.

Aix-Marseille University (AMU) is considered a pivotal data owner for both sub-demo cases as it contributes to the collection of diverse datasets. It provides in-situ data streams of soil humidity, linkages between carbon and nitrogen cycles, and runoff discharge to sewage systems. Standalone permanent air quality (AQ) sensors aimed to collect continuous observations of the particulate matter (PM) 1, 2.5, and 10. Subsequent soil sampling campaigns will be arranged to examine the soil pollutant concentrations and mesofauna density. Complementary to the sensor-driven data streams, participatory subjective citizens' perceptions of the NBS effectiveness and the flora and fauna species, will be collected. Eventually, AMU will provide HR point cloud datasets from LiDAR airborne missions, which will facilitate the implementation of topographic and hydrological studies, such as the runoff discharge assessment for both sub-demos.

Demo 5 will also capitalise on Local Climate Zone (LCZ) maps, land-use layer and urbanised heat spots produced by the Marseille Metropole, PACA and Nepsen/Marseille municipality, respectively, to investigate the urban heat island effect of the region. Auxiliary HR data layers such as cadastral parcel data and the VHR orthophotos will be obtained by the French government and the Institut National de l'Information

Géographique et Forestière (IGN-F). Finally, the EEA is a prominent European data owner for many demo cases so far and thus the CORINE LULC dataset will be exploited for these sub-demo cases, as well.

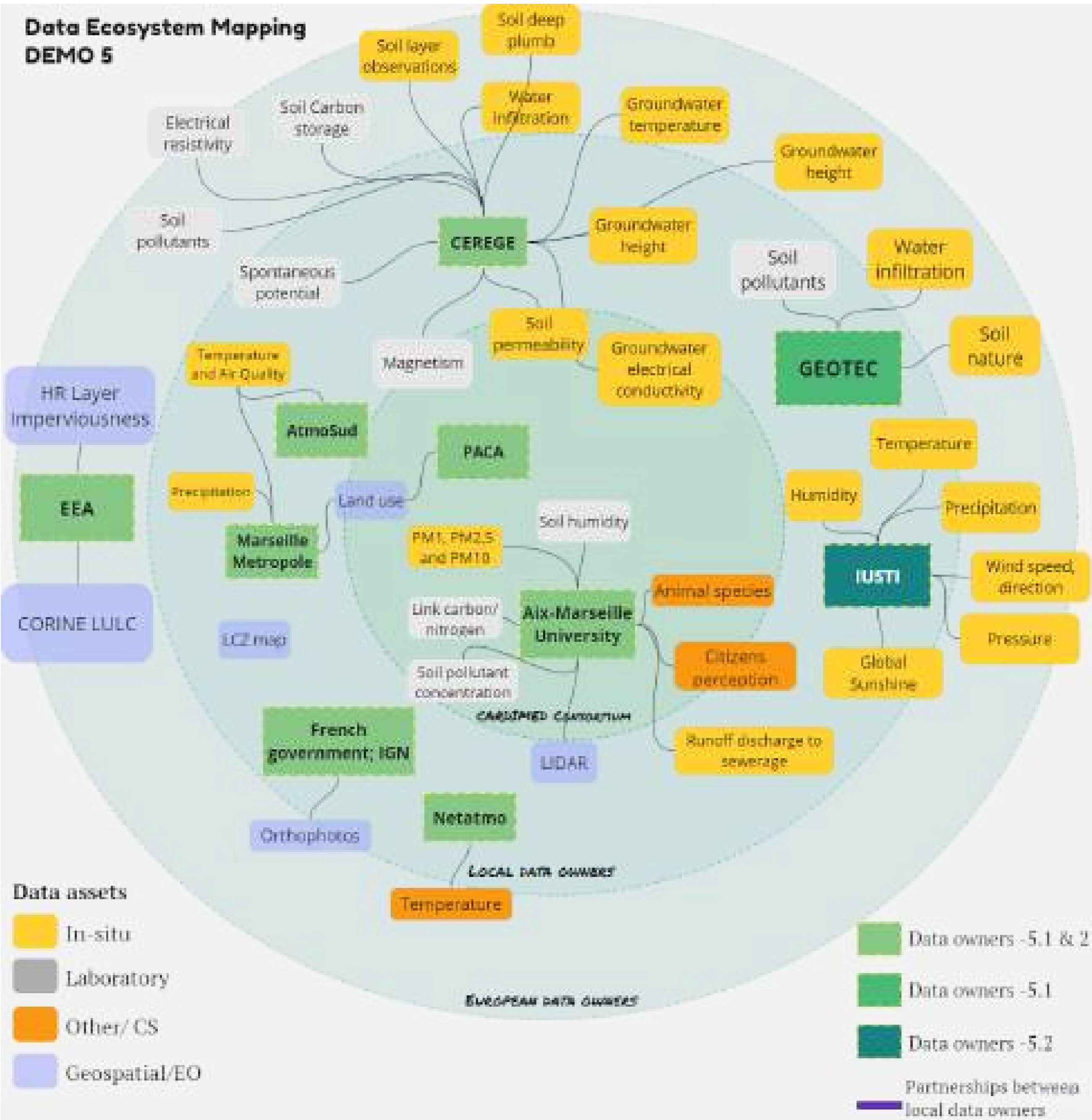


Figure 30: Data Ecosystem Mapping of DEMO 5, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers.

5.6.2 DEMO 5 Data Infrastructure

Analysing the data infrastructure of demo 5 (Figure 31), JSON/GeoJSON is the most widely adopted data format, as it is reported in 40 datasets (31 existing and 9 yet to be collected). Continuing, Microsoft Excel files are considered the second most chosen file format, which comprises a total of 31 datasets, spread between 21 existing datasets and another 10 planned. Another prominent format is ESRI shapefile with a total of 10 datasets fully available. Also, CSV files are utilised for lightweight data storage and exchange, especially for meteorological datasets, when ASCII or TXT files are not preferred. In handpicked cases of the geospatial vector-based datasets, more lightweight and recent file formats have been also adopted such as GeoPackage (4 datasets), FlatGeobuf (3 datasets), and Apache Parquet (3 datasets). Other formats that have been also reported are the GML (4 datasets) and NetCDF (1 dataset). As usual, rasterised data streams will be provided in TIFF/GeoTIFF or JPEG2000, while video records covered by citizens in MP4. Ascii /TXT and image files (JPEG, PNG) are used the least reflecting their niche in data sharing and documentation.

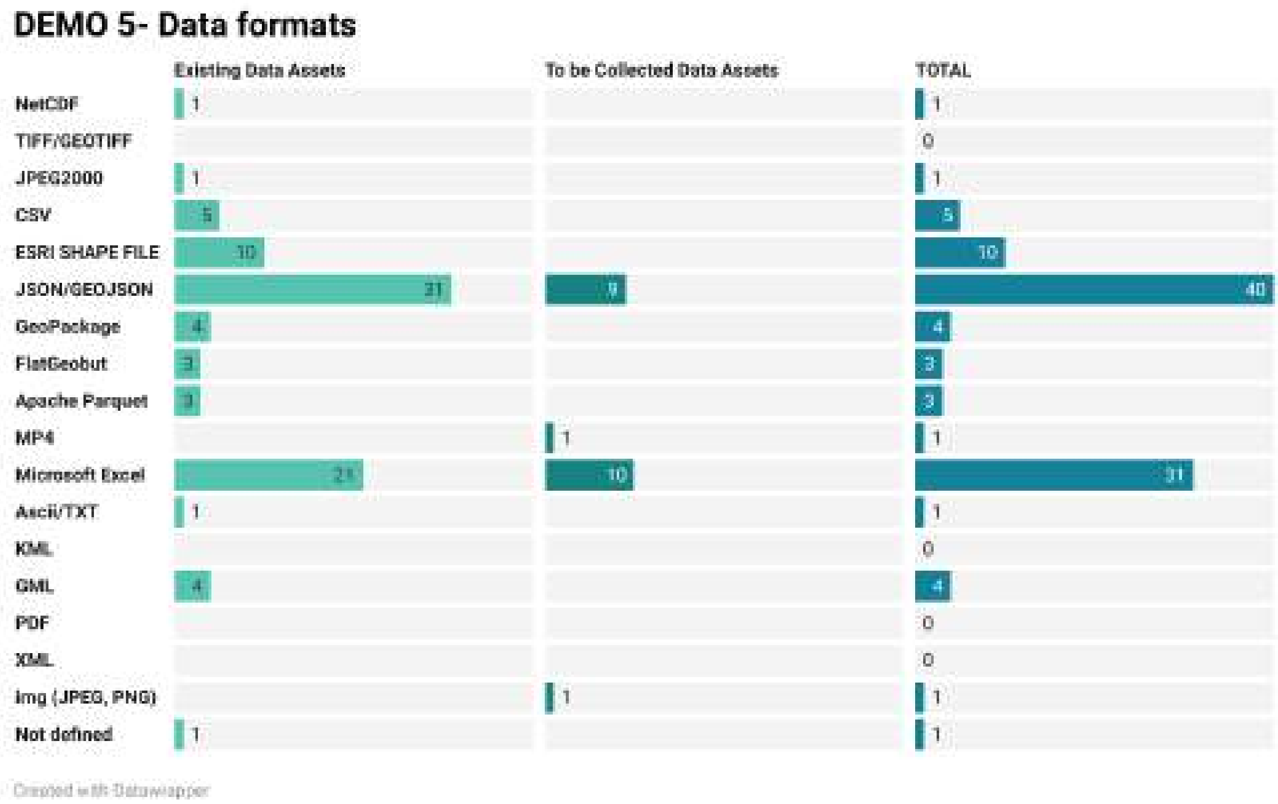


Figure 31: Data formats that have been chosen by DEMO 5 for storing the collected data.

Continuing with the data access interfaces (Figure 32), one secured file server will be employed by SEMIDE, which is the leader for the fifth demo case, for storing both the existing and the TBC datasets. In particular, 51 datasets in total have been declared, of which 40 exist and 11 are to be collected that are going to be provided by this specific interface. An alternative which is under investigation, is to capitalise on the centralised file server of the MW platform, avoiding the deployment of similar redundant infrastructure. Additional access points that are considered are the data portals/platforms, enabling smooth interface accommodation for nine datasets mostly provided by public authorities or governmental agencies. Standardised geospatial web services including OGC WMS, WFS, and WMTS have been reported in only a single case and thus we firmly believe that they will not be further exploited. APIs represent an up-to-date approach to data access, facilitating programmatic interaction with eight datasets.

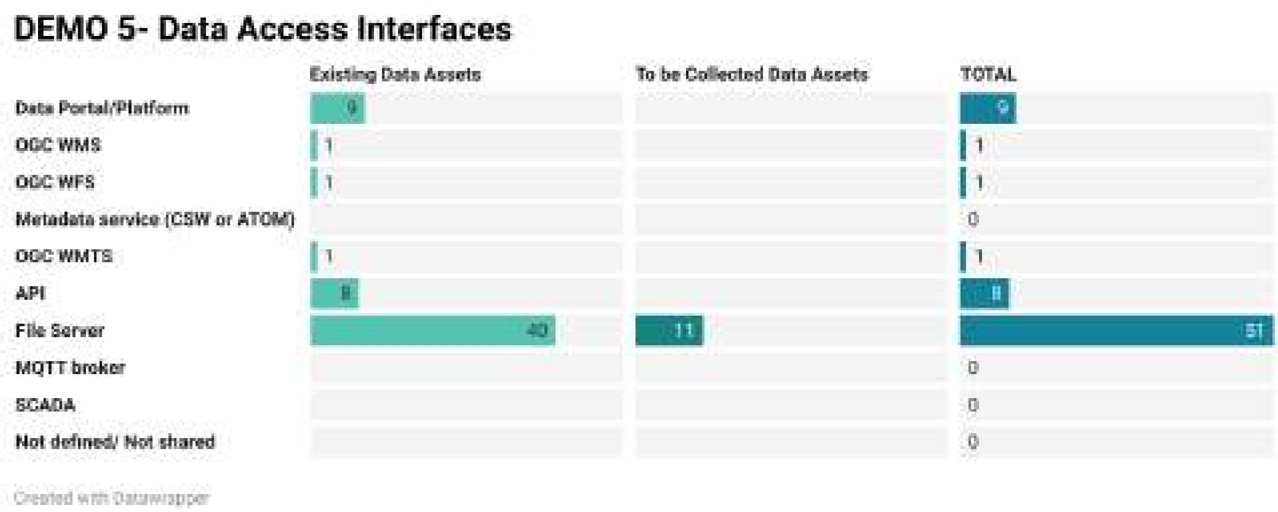


Figure 32: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 5 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6).

In terms of the temporal resolution (Figure 33), almost half of the cases i.e., 40% (24/63) will be collected continuously or on an hourly basis. For 15 cases (24%), demo leaders did not define the acquisition regime. Two reported datasets describing the historical meteorological observations are not expected to be frequently released and thus are denoted with an “irregular” update. Consequently, all the laboratory analysis results (7 cases in total) will be produced once a year, while the majority of the EO-driven or rasterised products are planned to be provided with a coarser temporal resolution, ranging from 2 years or even higher.

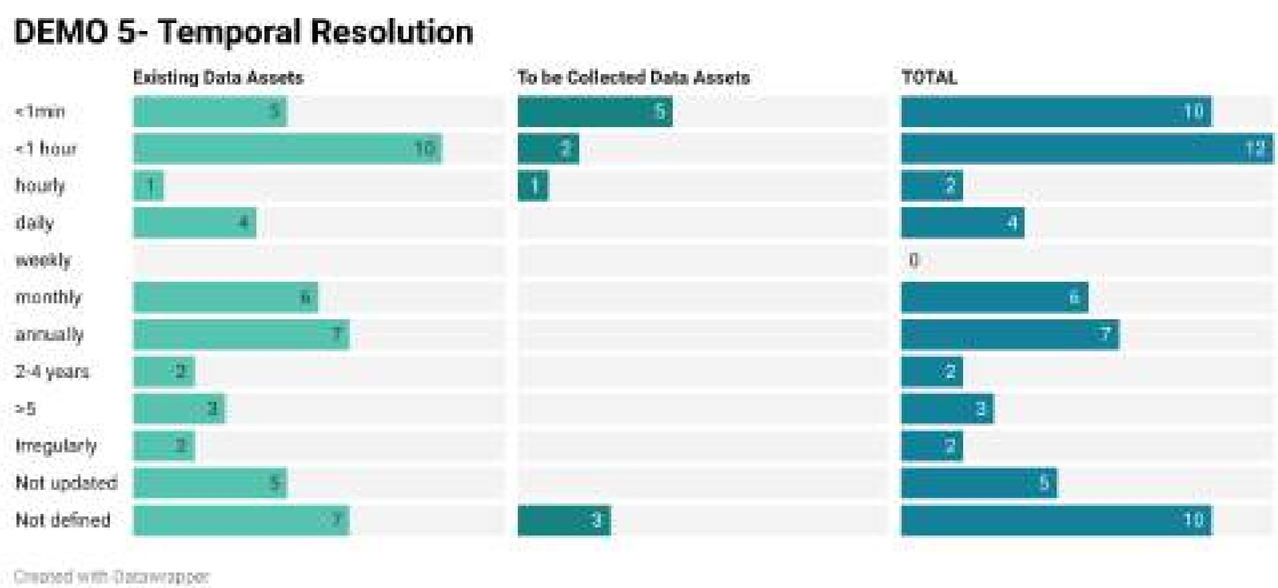


Figure 33: Illustration of the temporal resolution that the released data assets will have in DEMO 5.

Finally, as illustrated in Figure 34, in-situ observations stood out in this demo case as they express 74% of all the datasets (33 existing datasets and 11 upcoming data collection missions). When it comes to rasterised products, several spatial resolutions were found ranging from the VHR (2 cases in total) up to the ultra-low resolution of the simulated hydrologic reference projection layer.

Figure 34: Illustration of the spatial resolution that the released data assets will have in DEMO 5.

5.7 Discover DEMO6 Data Assets

5.7.1 DEMO 6 Data Ecosystem Mapping

The sixth demo case in the Aragon Spanish region is characterised by a significantly high concentration of citizens and an unsustainable urban centre, making the local society and the natural environment extremely vulnerable to heat waves. Furthermore, due to climate change, invasive flora species (mistletoe) have started to grow in the forested area of Aragon, disturbing the natural ecosystem and traditional agricultural activities. Addressing all the aforementioned, two sub-demo cases will be launched, with the first to be oriented on the restoration of the local ecosystem and the control of the invasive species in the Teruel forests and the second on the adaptation of public schools in Patios X El Clima in heat-wave episodes.

An indoor and outdoor in-situ sensing network will be installed in two primary schools gathering timeseries observations on temperature and relative humidity. As illustrated in Figure 35 the main contributor to the installation of the sensing monitors will be CIRCE. Complementary to the in-situ network, simulated solar radiation data will be generated to assess the impact of heat waves in schools. According to the literature (Wu, 2023), daytime heatwaves are associated with increased solar radiation, especially when the area is not affected by clouds and humidity. Besides the in-situ sensors, CIRCE plans to use the ENVI_MET software and perform simulations in order to evaluate the impact of the NBS solutions in the reduction of the urban heat island effect. For this purpose, external data sources will be exploited such as wind power and solar radiation, offered by the State Meteorological Agency (AEMET) and the Copernicus Data Space. Proper data transformations will be established in order to integrate the original data with the in-situ sensing data streams, into a common data model. Specific information on the data harmonisation and transformation process is provided in Chapter 6.6.

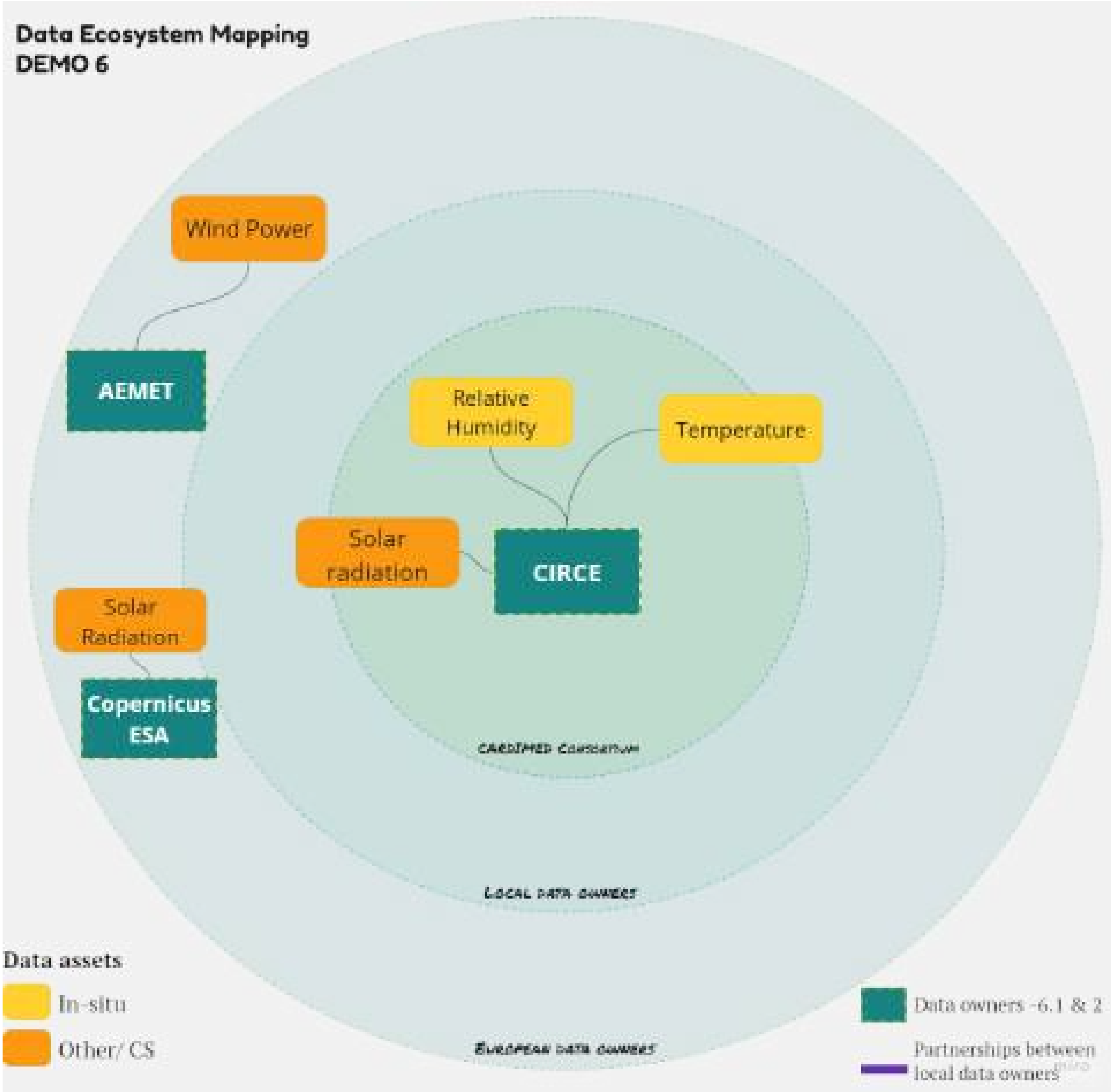


Figure 35: Data Ecosystem Mapping of DEMO 6, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers.

5.7.2 DEMO 6 Data Infrastructure

Continuing with the third step of the DLP methodology, the following paragraphs will shed light on the standards and technologies adopted by DEMO 6 for storing and accessing the collected data streams. Regarding the file storage formats (Figure 36), the collected in-situ data streams (3 reported cases in total) will be stored and therefore provided in the MW platform in JSON format. This concerns the temperature, relative humidity, solar radiation observations and the simulated solar radiation findings. Furthermore, the solar radiation data are provided by the Copernicus data space in Network Common Data Form (NetCDF) file format, while the wind power observations are available in both CSV and Microsoft Excel formats.

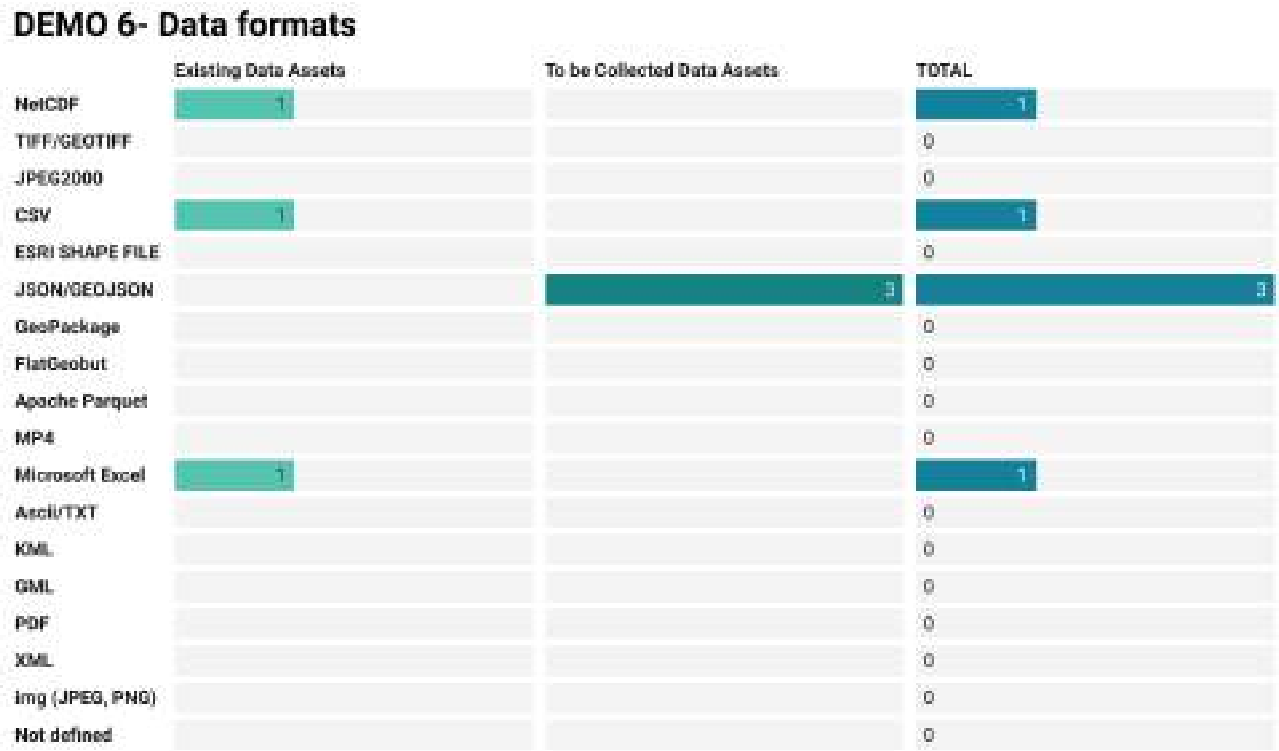


Figure 36: Data formats that have been chosen by DEMO 6 for storing the collected data.

Furthermore, in terms of the data accessibility interfaces (Figure 37), all the in-situ data streams will be transmitted using the MQTT protocol to a specific topic and will be finally stored in a relational database in the backend of CIRCE. All the existing data streams for the third-party external data providers will be accessible through the existing API interfaces. Additionally, AEMET also gives the possibility of downloading datasets through their available data platform.

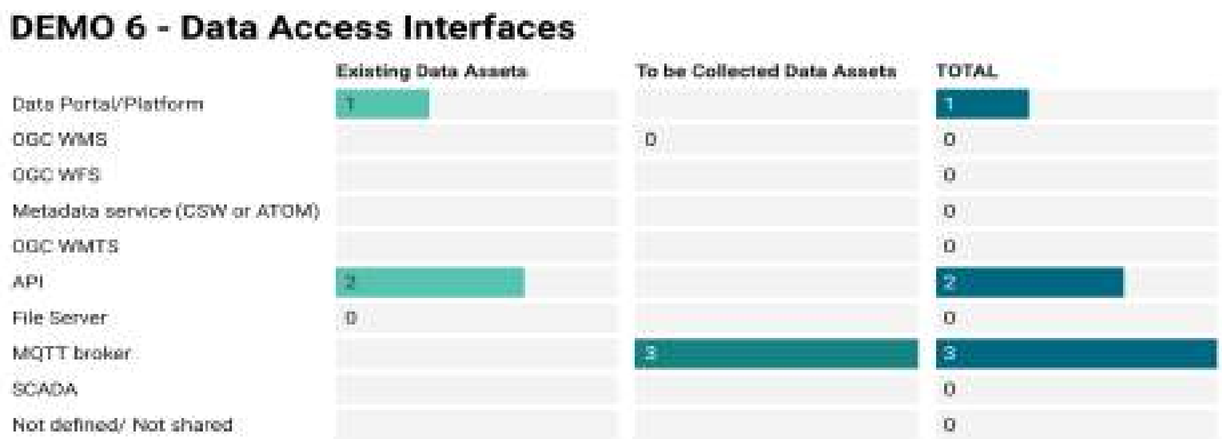


Figure 37: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 6 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6).

A positive outcome of this analysis revealed the high temporal resolution of the data collection as all data will be gathered on an hourly basis (Figure 38). Finally, when it comes to spatial resolution, the reported datasets fall into two categories, the pointwise in-situ observations and the rasterised products, which as presented in Figure 39 have a coarse resolution. This is a trade-off that normally appears on EO-ensembled datasets as they are the ones reported.

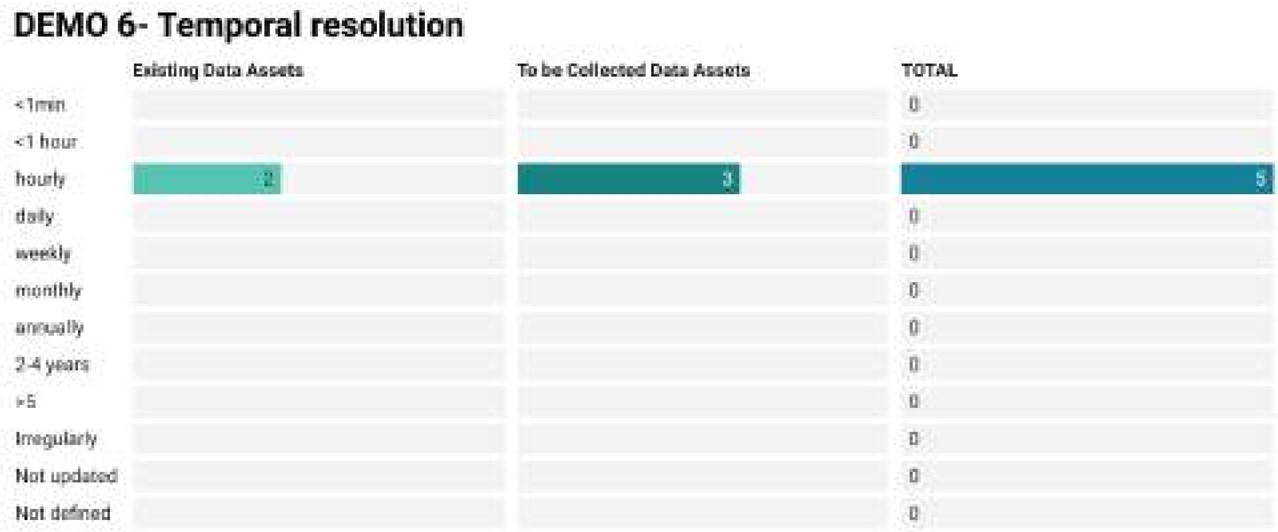


Figure 38: Illustration of the temporal resolution that the released data assets will have in DEMO 6.

Figure 39: Illustration of the spatial resolution that the released data assets will have in DEMO 6.

5.8 Discover DEMO7 Data Assets

5.8.1 DEMO 7 Data Ecosystem Mapping

The seventh demo case is deployed in the central Alentejo area in Portugal, which is described as the hottest and driest region in Portugal, and thus the abundance of water demands is now questionable. The Montado is a cultural landscape, which has been recognised by UNESCO as a natural cultural side of an outstanding universal value (UNESCO, n.d.). Nevertheless, during the past years, this specific region has been threatened by several climate change-related risks, such as increased temperature, droughts, water scarcity, soil degradation and biodiversity loss.

Concerning all the aforementioned, two sub-demo cases will be established, with the first focusing on restoring riparian woodlands and Mediterranean water streams and the second on the restoration of Montado’s native vegetation and agroforestry ecosystems. To assess the beneficial contribution of the deployed NBSs, bespoken data collection strategies will be initiated with the majority of the collected data to be attributed to local organisations As illustrated in Figure 40, a joint collaboration between the University of Évora and the Intermunicipal Community of Central Alentejo (CIMAC) will facilitate the collection of several ecological and biodiversity data streams. Indicative examples are the mapping of richness and cover of typical plant species, the tax of the planted trees and shrubs, the tree regeneration rate, the area of habitats and the invasive alien species (IAS). Complementary to the aforementioned data samples, in-situ meteorological variables of temperature and relative humidity will provide a broader recognition of the positive effects of NBSs.

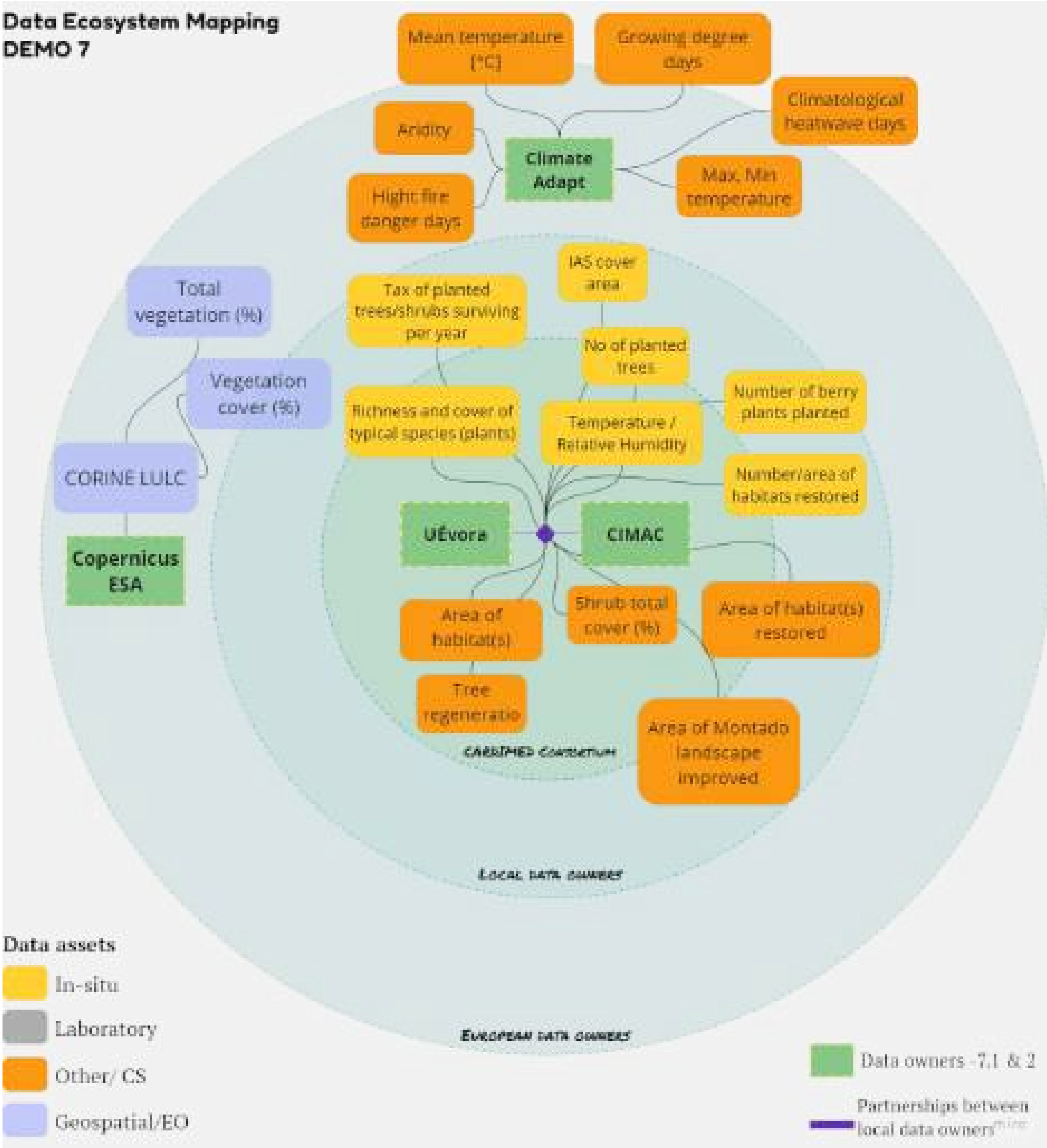


Figure 40: Data Ecosystem Mapping of DEMO 7, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers.

Continuing, the second sub-demo case includes data streams of the shrub total cover percentage, the area of habitats restored, and the improvement in the Montado landscape. On top of that, accurate measurements of the number of berry plants planned and the number and area of habitats restored will support the objectives of this sub-demo case with respect to habitat conservation and sustainable landscape management. Furthermore, EU data owners like Climate Adapt will provide various geospatial and climate data which serve as input to understand the regional climate and its implications. Key datasets include mean temperature, aridity, growing degree days, climatological heat wave days, and fires that pose risks. Finally, through the acquisition of the CORINE LULC of the Copernicus Land Monitoring Service, a subsequent layer will be created covering both sub-demo cases, measuring the percentage of the vegetation cover.

5.8.2 DEMO 7 Data Infrastructure

Commenting on the adopted data formats of the reported data assets of this demo case, Figure 41 illustrates that CSV is widely adopted for the collection of biodiversity data, both for the existing data assets (7 cases) and the upcoming ones (12 cases). Furthermore, this file format is also supported by the Climate Adapt service, which provides climate data related to the UHI and the heat waves. In 13 cases this information is also planned to be provided in a geospatial vectorised ESRI shapefiles. However, we assumed that also the CSV datasets would contain the specific coordinates, as these field samples will be in general pointwise. Finally, formats such as TIFF/GeoTIFF and JPEG2000 express lesser importance as they express 2 datasets in general.

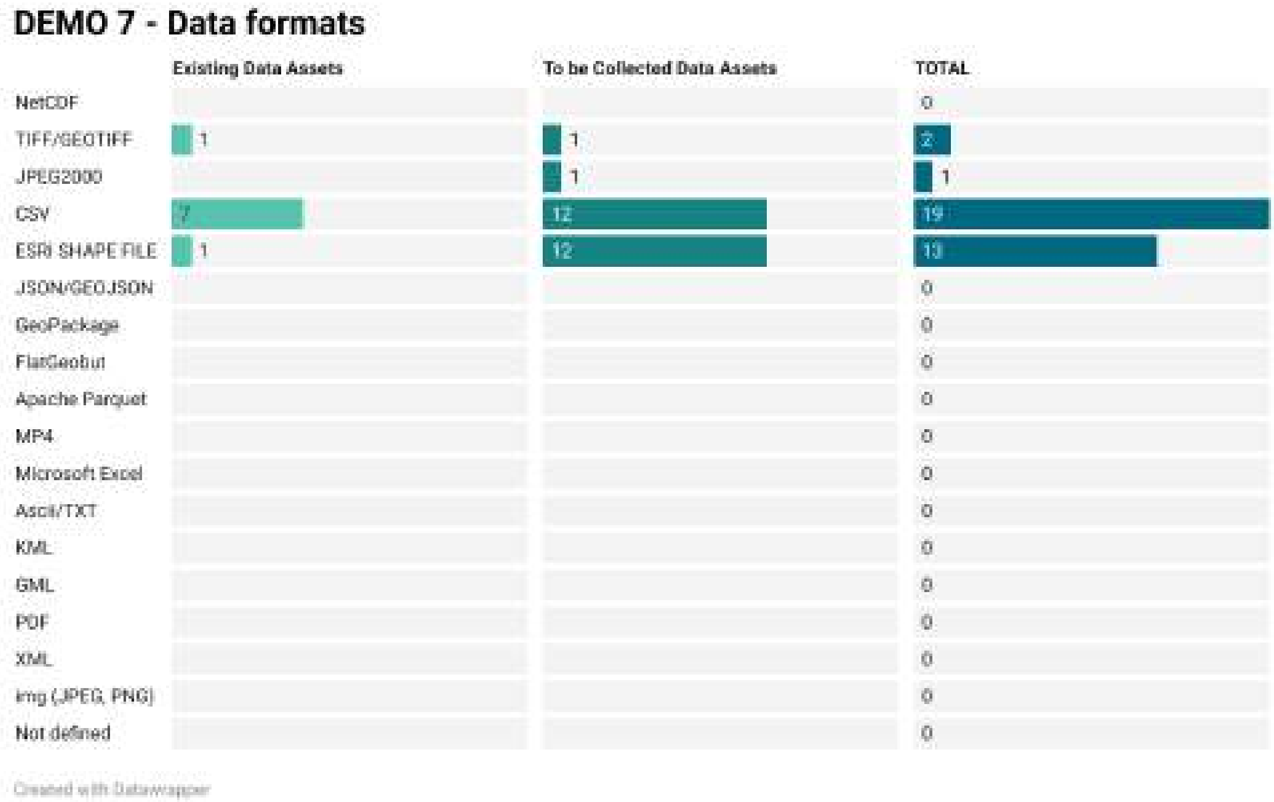


Figure 41: Data formats that have been chosen by DEMO 7 for storing the collected data.

All the aforementioned datasets will be manually collected and stored in the centralised file server of the MW platform. There is one single case, where temperature and relative humidity data will be collected continuously by one MX2301A sensor, which is accompanied by the HOBO mobile application. Both the sensor and the mobile application will be interconnected capitalising on the Bluetooth Low Energy (BLE) protocol. The acquired data streams will be transmitted using a 4G connection to the backend of the HOBO enterprise and will be ready for analysis through the HOBOware, a desktop application. For the data transmission in the MW platform, two manual mining processes will be implemented, in which initially data will be exported from the desktop app and then uploaded to the file server of MW. As presented in Figure 42, a more machine-friendly interface will be also explored by only three reported cases. This reflects the digitalisation maturity level of this specific demo case and the need to be substantially supported by the MW's respective partners.

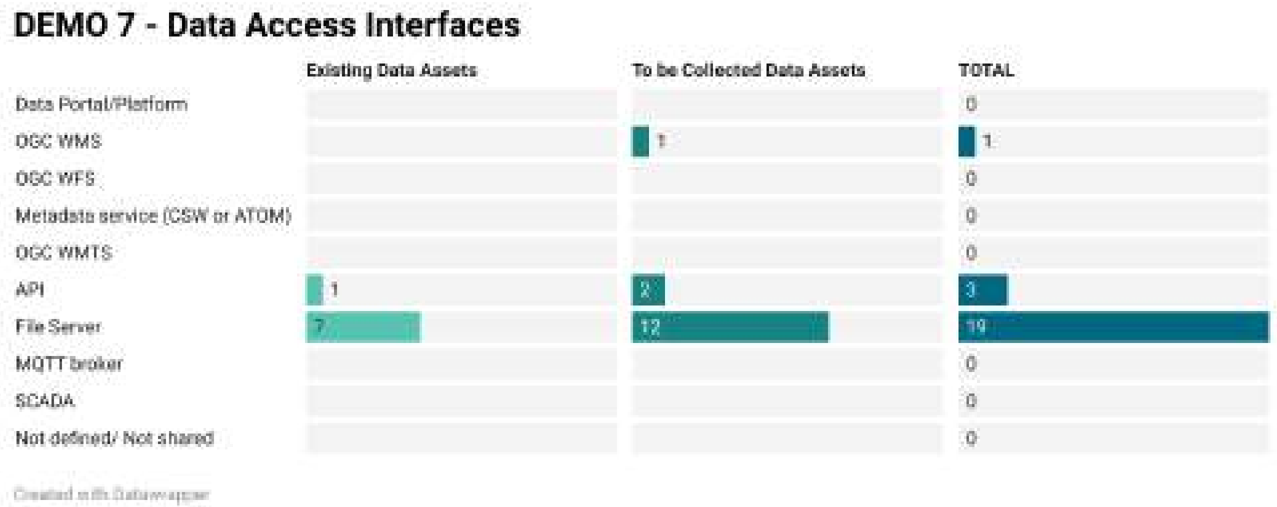


Figure 42: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 7 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6).

Furthermore, the temporal resolution analysis illustrated in Figure 43 highlights a general tendency to perform annual field data campaigns. The Climate Adapt service provides the climatological variables on a monthly basis. Only two data streams have been declared with a higher temporal resolution with the first to reflect the in-situ observations and the second the vegetation coverage.

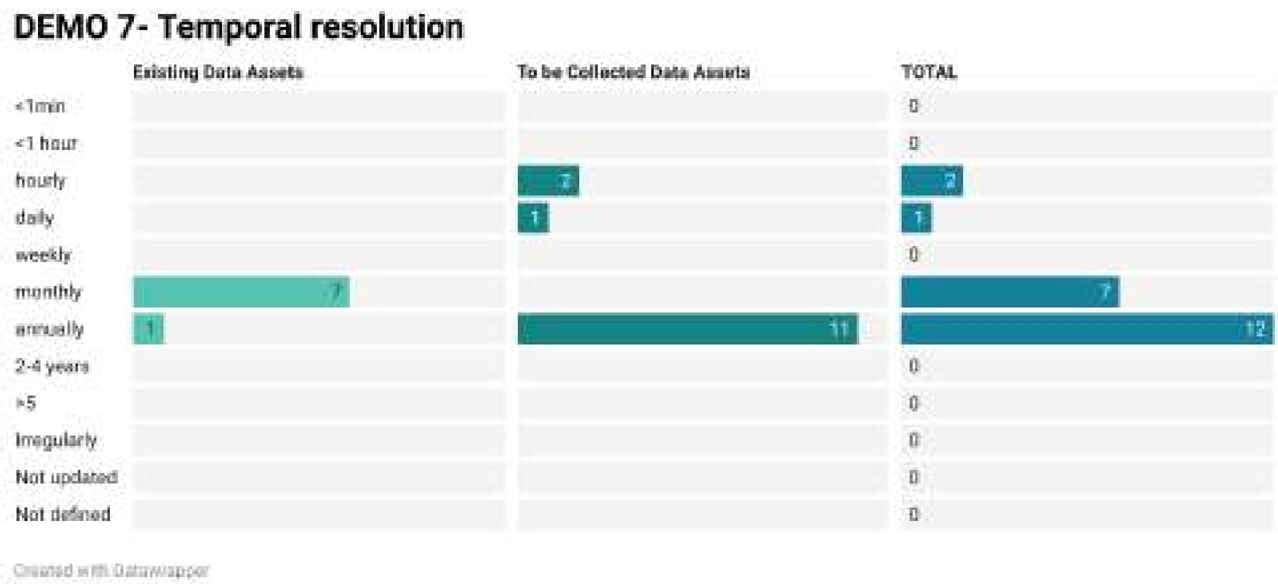


Figure 43: Illustration of the temporal resolution that the released data assets will have in DEMO 7.

When it comes to spatial resolution, the analysis of the identified data streams (Figure 44) showcases the diversity of data granularity. Most of the existing data assets are composed of "High" resolution datasets (7 assets, 5–30m or 25k–250k coverage) or point data (6 datasets in total). Only, one has been categorised in the "medium" resolution umbrella (30–300m or 250k–1M coverage) as the spatial resolution is approximately 100m. Lastly, there are no current assets that are point data with a very high (<5m or <25k) resolution or that are lower in resolution.

Figure 44: Illustration of the spatial resolution that the released data assets will have in DEMO 7.

5.9 Discover DEMO8 Data Assets

5.9.1 DEMO 8 Data Ecosystem Mapping

The eighth demo case of the CARDIMED project will be launched in the Gediz Delta (Izmir Providence) and it is characterized as one of the most critical wetlands in Turkey, where several fauna species are inhabited. Due to the intense climate change, this specific area is in a critical state, presenting severe alterations in soil salinity, sea level rise and shoreline erosion. In addition, invasive species flora species, like the Eucalyptus have spread throughout the whole wetland region, disturbing this way the natural environment. Reported studies have revealed that the aquatic and land fauna species are at risk due to the degradation of the local ecosystem and in particular the decreased quality of pastures and disappearance of Juncus habitats.

Considering all the aforementioned climate change-related threats, DEMO 8 will demonstrate a series of NBS interventions, willing to restore the natural environment of the area. To evaluate the effectiveness of the deployed NBS interventions, a plethora of data streams will be collected with the majority of them to be acquired by the pilot partners of the CARDIMED consortium. As presented in Figure 45, this demo outlines a collaborative partnership between the five demo partners, i.e., Izmir Metropolitan Municipality (IZMM), DOGA Nature Association (DOGA), IzDoga and General Directorate Of Izmir Water And Canalisation Authority (IZSU). All of them are focused on the assessment of the natural restoration of the area. On the contrary, İzmir Institute of Technology (IZTECH) will assess the improvement in soil quality and the benefits of introducing sustainable energy production facilities.

In particular, Doga and IZSU will organise several field campaigns to measure the fauna species in wetlands. Handpicked examples are amphibians, odonates, medium and large mammals (e.g., goats and sheep), reptiles, European hares and regular birds' presence. For the latest, a comprehensive dataset called "breeding bird atlas" already exists, with information related to the distribution of bird species throughout the globe. Additional focus will be given to the assessment of illegal poaching activities. Izdoga and IZMM organisations will perform field campaigns and thus report the total vegetation coverage of the region and the livestock capacity by counting the herbivorous wild mammals. Finally, IZTECH will deploy in-situ soil quality sensors to gather groundwater and soil quality variables (e.g., groundwater level, electrical conductivity and water temperature). Extensive laboratory analysis will be performed to determine pH, electrical conductivity, anions (Cl−, NO3−, NO2−, SO4−2, CO_3^{-2}, HCO3-), cations (Ca+2, Mg+2, Na+, K+), and heavy metals. Eventually, a static weather station is foreseen to be installed and gather continuous meteorological observations. Complementary meteorological observations will be acquired from the General Directorate of Meteorology, which is under the Ministry of Environment, Urbanisation and Climate Change. Finally, the CORINE LULC dataset will be exploited from this demo case as well.

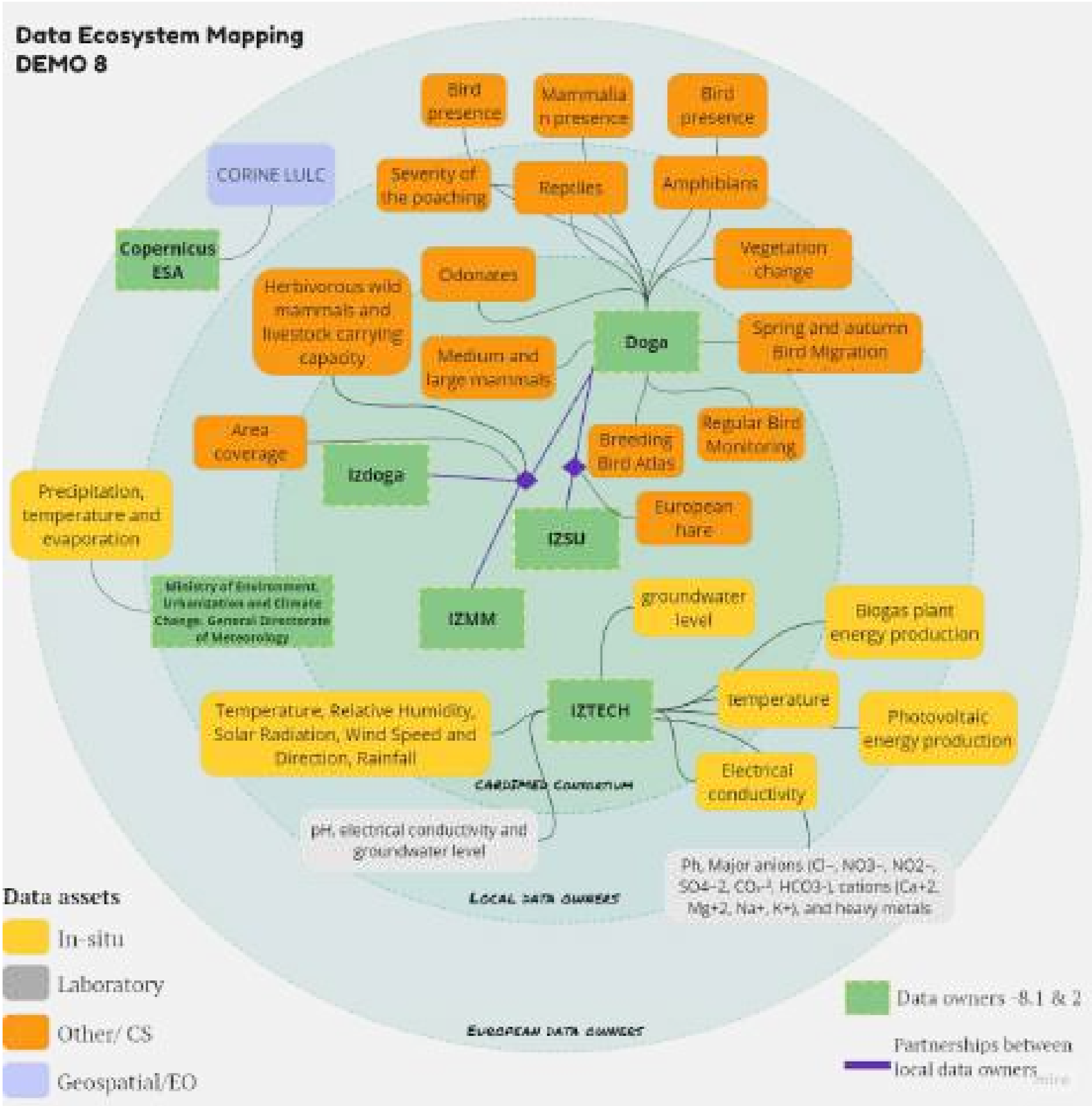


Figure 45: Data Ecosystem Mapping of DEMO 8, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers.

5.9.2 DEMO 8 Data Infrastructure

The DEMO 8 case relies heavily on well-structured data structures to ensure complete digitalisation and seamless data with the MW platform of CARDIMED. As depicted in Figure 46, DEMO 8 reflects a diverse mix of storage formats addressing the complexity of the generated information. Microsoft Excel was proven the most dominant file as it will be used for the majority of the collection campaigns (11 in total). This expresses datasets from laboratory analysis, soil sampling campaigns, and the observations of flora and fauna species. It is considered an upgraded digitalised solution from the former ones, where the collected observations were reported in PDF format (5 existing datasets). Occasionally, the more advanced CSV file format will be used (8 total cases: 2 existing and 6 upcoming datasets), for the outcomes of the laboratory analysis and meteorological timeseries observations. Continuing, TIFF/GeoTIFF, ESRI Shapefile, and JSON/GeoJSON reflect a minority for this demo case as it describes only 3 cases in total. Eventually, Doga keens to offer video records on the mammalian presence in MP4 format.

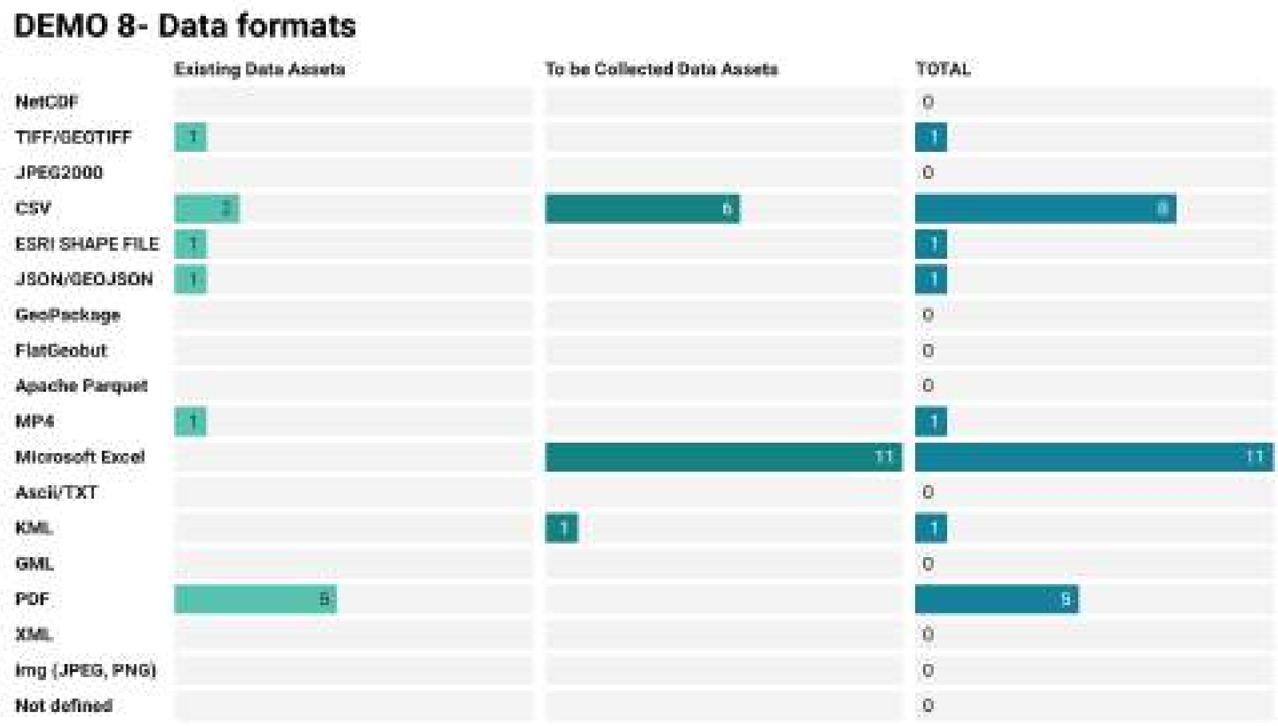


Figure 46: Data formats that have been chosen by DEMO 8 for storing the collected data.

When it comes to the data access interfaces (Figure 47), DEMO 8 is dominated by the centralised file server of the MW platform as it expresses the data submission in 24 reported cases (7 existing and 17 to be collected datasets). This preference highlights the absence of any existing machine-useable infrastructure for data transmission. Continuing, APIs are considered the second favourable option reported 3 times in total. They mostly describe the cases of the eBird service and the Royal Eijkelkamp's soil and water in-situ sensors that are going to be utilised in order to receive measurements for the quality and groundwater level in wetlands. For the second technological solution, two options are provided with the first being the data transmission through an API as earlier described and the second the File Transfer Protocol (FTP). Finally, the CORINE LULC provided by the EEA and the meteorological observations from the Ministry of Environment, Urbanization and Climate Change are considered to be provided from a data portal.

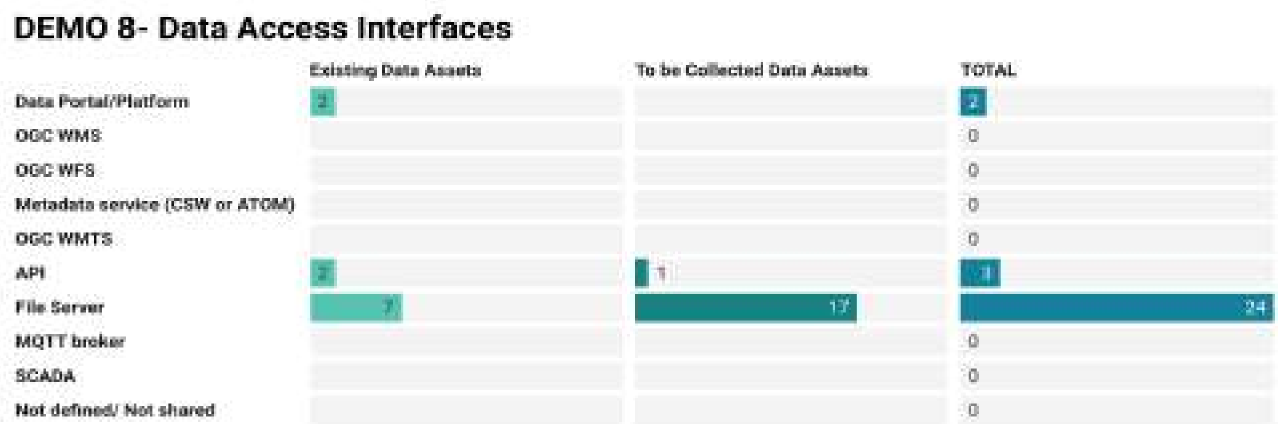


Figure 47: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 8 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have

deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6).

Furthermore, analysing the temporal characteristics of reported datasets (Figure 48), we witnessed a general ambition to reduce the time gaps between the different data acquisitions. More specifically, the majority of existing datasets are described with a coarse temporal resolution as they are collected once a year (5 reported cases) or even created once with no intention for updates (1 dataset). Additionally, the measurements of bird and mammalian presence were not accompanied by the specific time and thus are classified in the "Not defined" category. On the contrary, the upcoming datasets present completely different characteristics. Five datasets reveal a significant improvement in the reduction of the timespan between the different acquisitions, ranging from the unstoppable collection (< 1 minute) up to daily collection plans. Nevertheless, the annual data acquisitions remain the dominant preference of this demo as it describes 10 datasets in total.

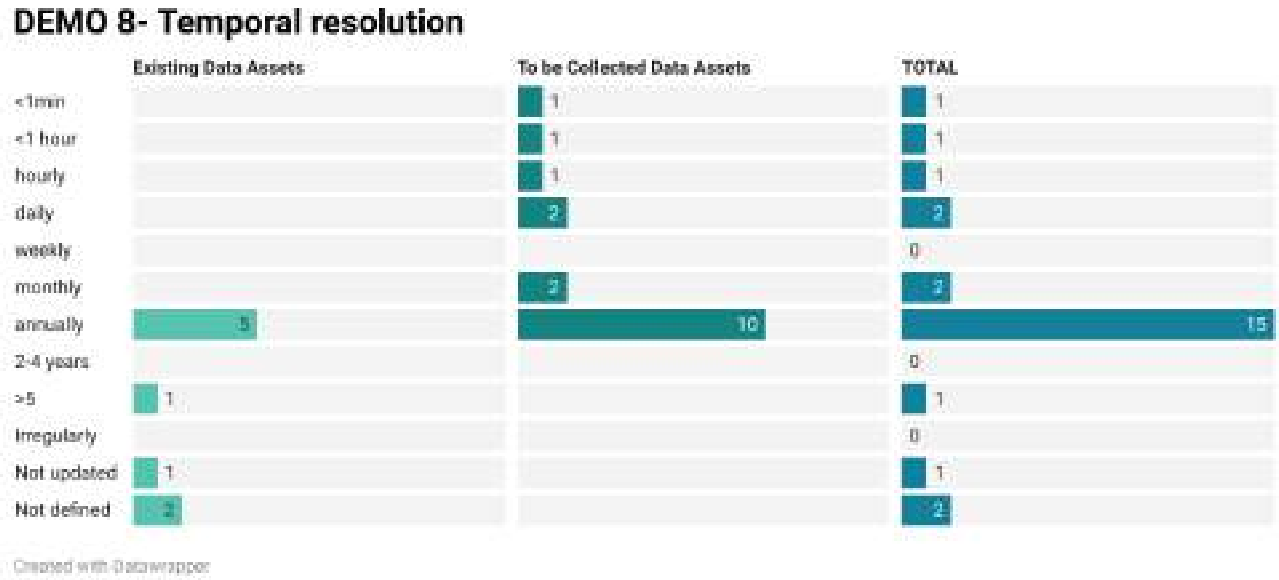


Figure 48: Illustration of the temporal resolution that the released data assets will have in DEMO 8.

Finally, when it comes to the spatial resolution (Figure 49) in both existing and the "to be collected" datasets the majority of datasets will be point-wise observations, and thus any further analysis is not applicable for this characteristic. There are only 4 datasets, which are classified into high, medium and ultra-low spatial resolutions and these correspond to the vegetation cover (10x10m), CORINE LULC (100m), the Breeding Bird Atlas (1x1 km) and the mammalians' presence (1x1 km).

Figure 49: Illustration of the spatial resolution that the released data assets will have in DEMO 8.

5.10 Discover DEMO9 Data Assets

5.10.1 DEMO 9 Data Ecosystem Mapping

The final demo case of the project is located in the capital of Cyprus and is characterised by a severe degradation of the urban and natural landscape due to climate change. Increased temperatures, droughts and fluctuations in rainfall events, as well as sea level rise, can be considered as handpicked examples of the threats that endangered the longevity of the local area and the quality of life. Coping with these challenges, three sub-demo cases will be launched in three public spaces, (a) the Gardens of the Future, (b) the Makrigiannis Park, in which a phytoplankton treatment will be formulated, and (c) the Anthis Christophidou park, where a subsurface rainwater harvesting system will be used. Further details on the NBS treatments of all three sub-demo cases are available in D2.2.

For all the aforementioned sub-demo cases in the Cypriotic region, a well-designed data collection strategy will be established with the participation of mainly the consortium partners of the project. As illustrated in Figure 50, three main organisations will be responsible for gathering critical in-situ and laboratory data streams that are essential to evaluate the effectiveness of the deployed nature-based solutions. Starting with the existing data assets that are going to be provided by the external local data owner, Smart Sense will lead the objective of this demo case in observing the air quality conditions of all the areas. In particular, an already installed in-situ network of weather stations will be utilised and monitor key parameters of air quality. Indicative paradigms are the meteorological variables of temperature and relative humidity, which reveal the evolution of the urban heat island effect. Measurements of the atmospheric pressure will assess the air conditions and the circulation throughout the urbanised landscape. Furthermore, noise levels are also recorded the noise pollution, a newcomer threat in urban environments as it degrades the living conditions of citizens. In addition, the distribution of atmospheric pollutants such as carbon dioxide (CO_2), sulphur dioxide (SO2), nitric oxide (NO), nitrogen dioxide (NO2) and ozone (O3) can be denoted as the cornerstone data asset of this organisation and thus the major attention is towards in this direction. Finally, the distribution of the particulate matter with particle sizes of 1, 2.5 and 10 will complement the holistic inspection scene of all sub-demo cases.

Continuing, a joint partnership will be initiated between EBOS and the municipality of Lefkosia and thus will deploy a dense network of in-situ sensors. For all three sub-demo cases, critical parameters will be monitored that are related to microalgae cultivation, the assessment of the reclaimed water from the harvesting system and the cultivation of the vertical gardens. This encompasses the pH, the internal temperature of the treatment, chlorophyll, ambient temperature, relative humidity, precipitation, wind speed, gust, and direction and atmospheric pressure. Overall, this describes a complete weather station that is going to be installed in the vicinity of the NBS. Solar radiation measurements will provide insights regarding the energy that is captured and used, while the UV index will assess the radiation exposure of the tap water during the infiltration process. Finally, soil and water sensors will gather hydrological data on conductivity, turbidity and soil moisture, respectively. Complementing the in-situ sensing monitoring, dedicated laboratory experiments are planned to assess the biomass produced, nutrients in the soil and water, such as nitrate, ammonium and phosphate, metal and minerals, and therefore the chlorophyll content. The aforementioned laboratory analysis will be implemented for the second sub-demo case, as well. Finally, tailored water level sensors and flowmeters will be deployed in sub-demo 9.2 to assess the water level in tanks and the flow rates in the rainwater harvesting system.

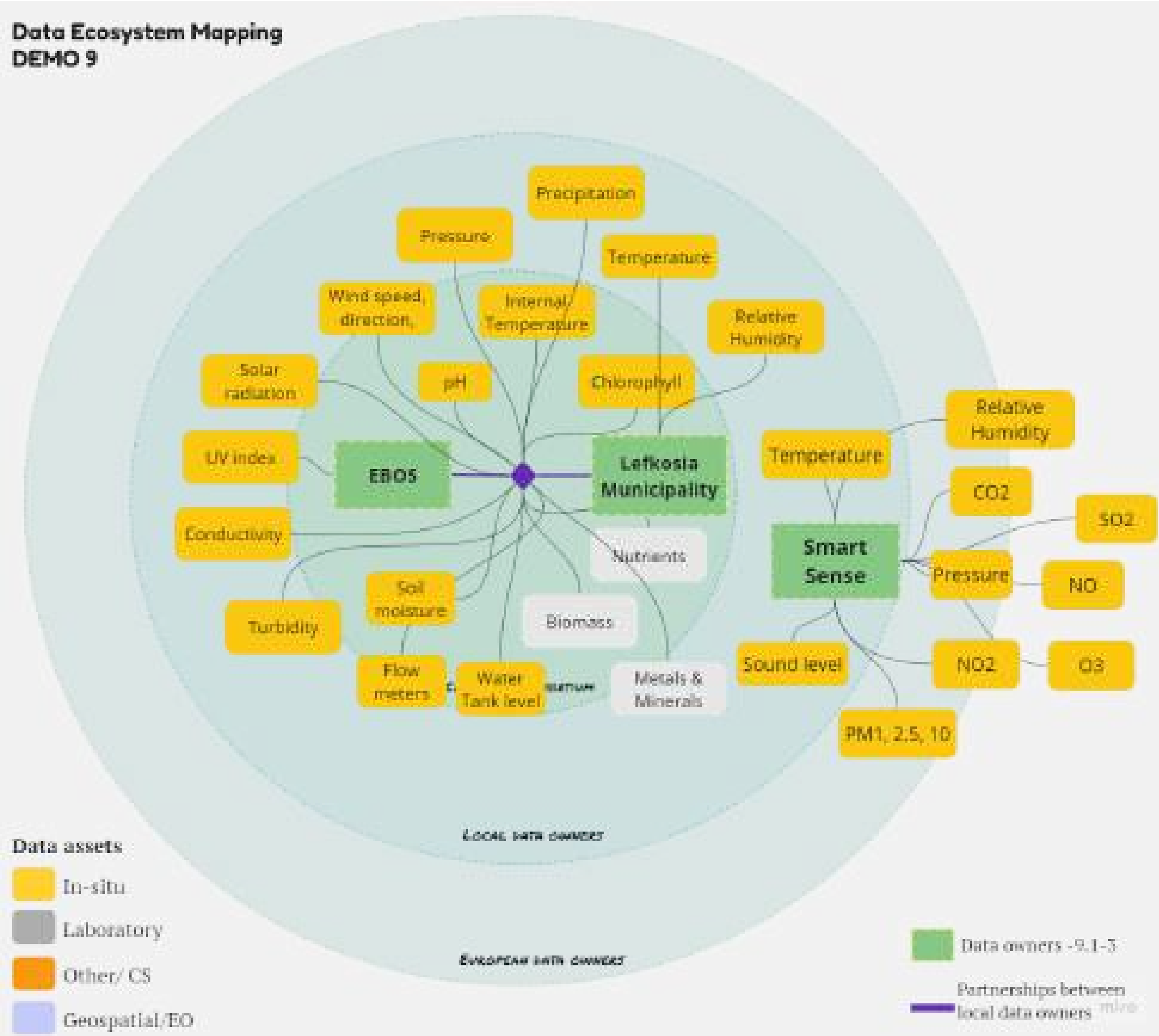


Figure 50: Data Ecosystem Mapping of DEMO 9, presenting with different colours the data types, the main data owners as well as existing partnerships for the production of a data source. The data owners are further categorized in case they belong to the CARDIMED consortium or are external local or EU data providers.

5.10.2 DEMO 9 Data Infrastructure

The data infrastructure of DEMO 9 will follow a common strategy and all datasets will be stored in JSON formats (Figure 51). An exemption of the aforementioned general tendency is reported for 6 cases, which mostly describe the generated datasets from the laboratory analysis. For these cases, the CSV file format is going to be used. Regarding the data accessibility interfaces, three main approaches will be established. According to Figure 52, existing datasets, provided by Smart Sense are going to be distributed through the pre-existing client-server interfaces (i.e., API). For the upcoming data collection of the in-situ monitors, a local system will be deployed with MQTT brokers to be responsible for the data transmission in the MW platform. All the sensors are going to send the collected measurements to be MQTT broker capitalising on the local lightweight Long Range Wide Area Network (LoRaWAN). Finally, the results from the laboratory analysis will be manually uploaded to the centralised file server using the specially designed GUI.

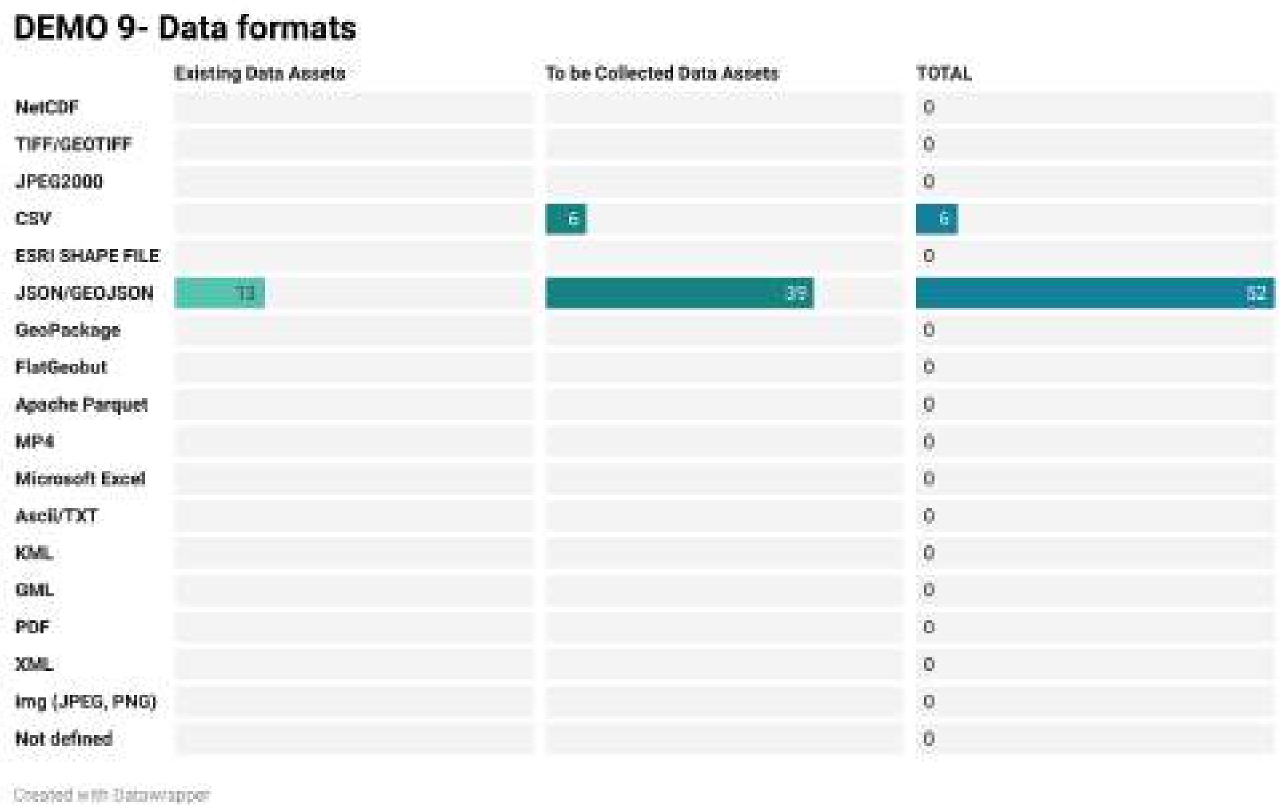


Figure 51: Data formats that have been chosen by DEMO 9 for storing the collected data.

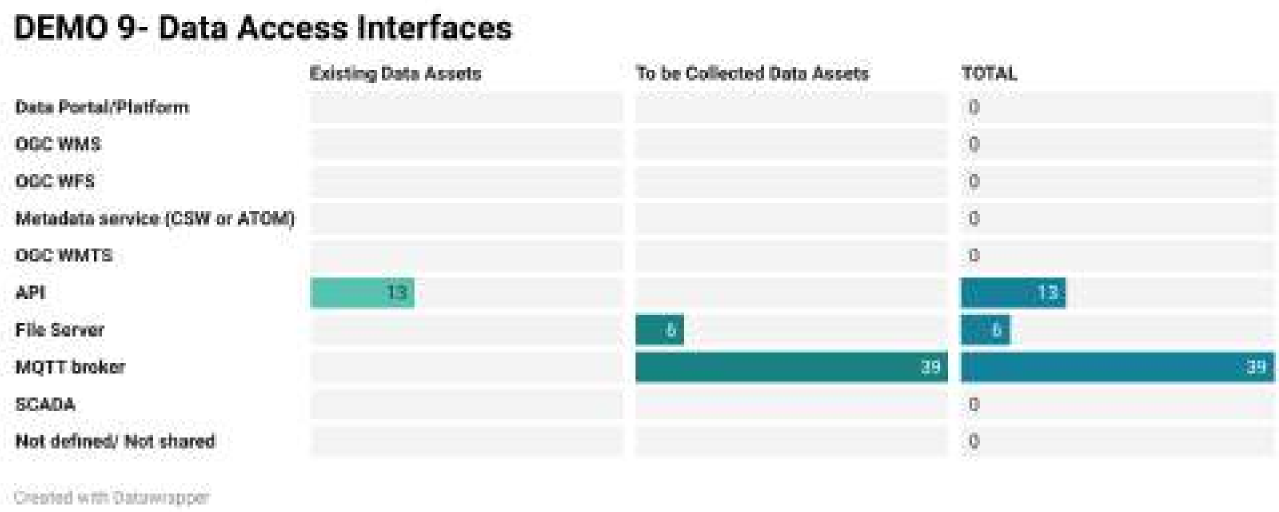


Figure 52: Chosen interfaces (User or Machine-readable), under which data collected in DEMO 9 will be available and distributed to the Middleware Platform of CARDIMED. This encompasses cases where the DEMO-related partners have deployed already an infrastructure or cases where data will be stored in the Middleware by manual (or semi-manual) data upload to the centralised file server (see further details in Chapter 6).

Continuing, the majority of the observations will be acquired by the static in-situ sensing monitors and thus the data collection process is planned to be constant and on an hourly basis (Figure 53). On the other hand, the laboratory examinations will be organised every 2-3 weeks based on the samples and the quality of the given results. Finally, as can be normally implied, a spatial resolution analysis is not applicable for this demo case as all the acquired datasets arise from pointwise sensors (Figure 54).

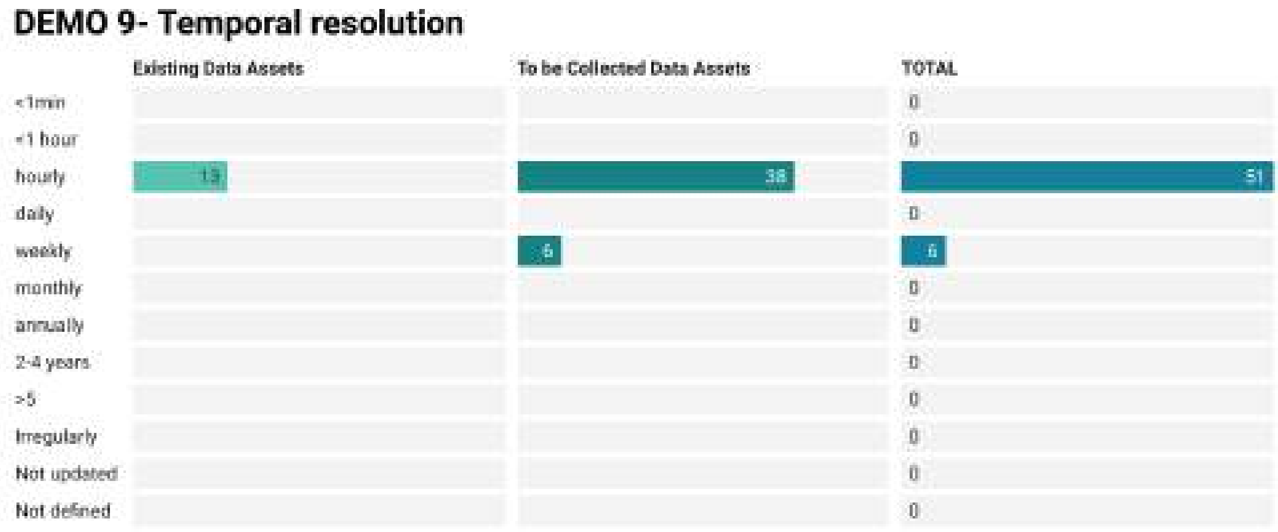


Figure 53: Illustration of the temporal resolution that the released data assets will have in DEMO 9.

Figure 54: Illustration of the spatial resolution that the released data assets will have in DEMO 9.

5.11 Data Ethics Canvas of CARDIMED's DEMOs

5.11.1 Data Openness

Open Knowledge Foundation (OKF) denotes data as Open when it "can be freely used, modified and shared by anyone for any purpose" (Open Knowledge Foundation, 2015). The aforementioned term seems to be highly correlated with the FAIR (Findable, Accessible, Interoperable, Reusable) principles, (Wildman & Lewis, 2022), which are also described in D1.2. Consequently, the ODI introduced the concept of Data Spectrum to demystify the data language, but most importantly to assist the data owners or custodians in defining the degree of freedom of using, accessing and sharing datasets, and to what extent it is appropriate (OpenActive, 2024). Besides the definition of open data, ODI introduced two additional types, Shared and Closed. In the first category, data are shared with others under a specifically determined licence between the beneficiary members, while in the second data cannot be shared and are explicitly used only for internal purposes.

During the last few years, we have witnessed a general tendency in releasing data openly, and thus reduce the cross-broader data silos. Towards this aspect, the World Bank defined two discrete dimensions of data openness, i.e., the legal and the technical openness. The first one refers to the necessity of defining the legal constraints of using, modifying and accessing data by the wider public for the official release, while the second encourages the adoption of electronic data formats that allow everyone to access them using freely available software tools. All in all, data is particularly useful when they are reachable and can be found and used. This indicates that a data asset should be agnostic. Achieving these high standards for the design of each data source can support the decision-making process and address more effectively a wide range of environmental and societal challenges (Spatial Data Provenance Guidelines for NBS, 2023).

Considering all the aforementioned, this chapter aims to review the intention of the data providers in releasing their data sources openly. Since we are at an early stage of this project, the complete analysis towards this aspect will be provided in the final version of the data management plan (M54). The same also should be stated for the technical openness, as at this stage only a minority of the existing reported datasets are available through Open Data Catalogues, or in general public interfaces. Nevertheless, we firmly believe that this analysis as well as the one in the chapter that follows paves the way for the DEMOs to adopt the data openness perspective and therefore guides them on the different licences, which they will wish to choose based on the level of freedom in use, modification and alteration of the initial product they wish to provide.

Continuing with the analysis of the level of openness in all DEMO cases (Figure 55), a mixed landscape is presented, standing from a complete intention of the DEMOs to openly release their data-driven findings up to the completely opposite perspective. The highest percentage of openness is presented in DEMOs 6 and 7 (100%), with a significant intention towards this pathway to be also seen in DEMOs 8 and 9, as they reached 70% and 77%, respectively. An opposite scene is illustrated in the remaining demos, with the most restricted to be DEMO 2. HALCOR declared from the very beginning of this project that all the generated datasets will be highly confidential. One exception is only expected, due to the partnership with CORE and only for the development needs of the DDIWSS. Less restrictive is foreseen to be DEMO 3, as datasets will be shared but not with the general audience, and in particular without any specific agreement. DEMO 4 illustrates a slight effort to democratise its results, but this is presented only in the existing datasets owned by the government agencies of Sicily, such as the Civil Protection Department Sicily Region, the Regional Territorial Information System, the Revenue Agency, etc. The consortium partners have chosen to keep datasets closed at this stage of this project or shared within the consortium. Finally, DEMOs 1 and 5 have resulted in similar percentages with their general perspectives to maintain their datasets closed or only accessible within the consortium as imposed in the Consortium Agreement (CA).

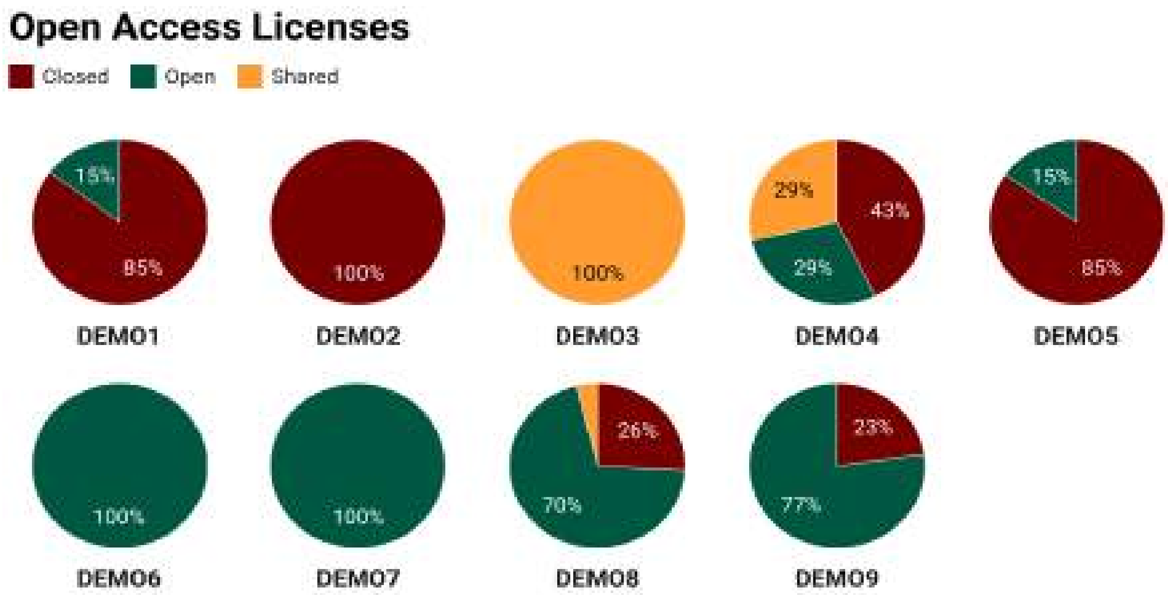


Figure 55: Distribution of the data assets in the three categories of Data Spectrum (open, shared and closed).

Considering the technical openness, it usually examines the extent to which the Open Data Portals or Catalogues of the data providers adopt the FAIR principles. In the majority of the reported cases, such an analysis seems inapplicable since it wasn't the main objective of this task and thus the reported datasets are not stored in public data portals. Nevertheless, indicative examples are presented in Table 11, analysing FAIR compliance using the online software FAIR-checker (FAIR-Checker, 2018). As can be seen, only two demos expressed the intention to incorporate datasets that are provided by governmental open data portals. All three examples have reciprocal poor results in the four directions of FAIR, indicating the need for further improvement in all directions with the greatest attention to be required in the last (i.e., Reusable).

Table 11: Assessment of the FAIR compliance level in the reported local Open Data Portals/Catalogues. EU data providers are not imported in this analysis.

	Identified Open Data Portals	FAIR compliance
DEMO 1	No open data portal was reported	Not applicable
DEMO 2		
DEMO 3		
DEMO 4	S.I.T.R - Regional Territorial Information System: URL	**TOTAL FAIR assessment: 25% [Accessible:** 50%; **Findable:** 40%; **Interoperable:** 16.7%; **Reusable:** 0%]
DEMO 5	AtmoSud: URL	**TOTAL FAIR assessment: 25% [Accessible:** 50%; **Findable:** 37.5%; **Interoperable:** 16.7%; **Reusable:** 0%]
	Aix-Marseille Provence Metropolis Data platform: URL	**TOTAL FAIR assessment: 50% [Accessible:** 50%; **Findable:** 62.5%; **Interoperable:** 50%; **Reusable:** 33.3%]
DEMO 6	No open data portal was reported	Not applicable
DEMO 7		
DEMO 8		
DEMO 9		

5.11.2 Open-accessed licences

The second chapter of the data ethics canvas attempts to further delve into the open-accessed licenses that have been established only on the datasets declared by the demo leaders as open. Addressing the aspect is of paramount importance to the whole consortium of CARDIMED as it provides specific information on the level of freedom that any additional user can have upon accessing each data source, avoiding this way any unforeseen ethical implications. Additionally, it provides for every demo case a preliminary direction over the licenses that are commonly used in their local districts, which they might consider using for the upcoming generated datasets. The results of this process are depicted in Figure 56 and Table 12 in more detail.

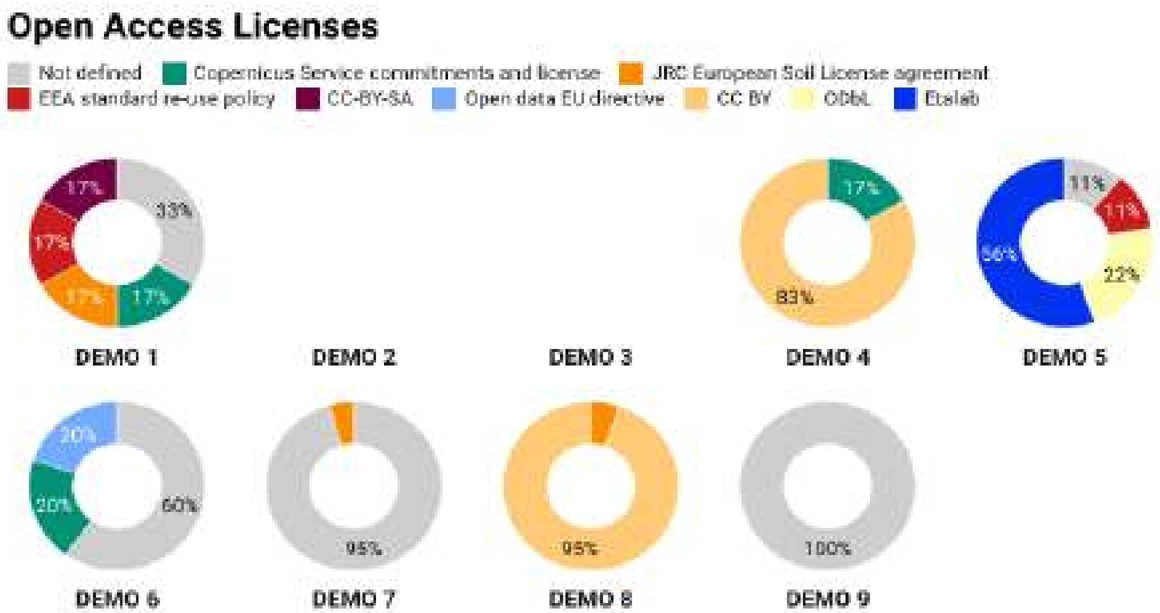


Figure 56: Open-accessed licences that have been chosen by the data owners of every DEMO for the reported data assets.

Table 12: Distribution of the open-accessed licenses for the reported data assets across the 9 DEMO cases.

Licenses	DEMOs									TOTAL
	1	2	3	4	5	6	7	8	9	
Copernicus Service commitments and license	1	0	0	1	0	1	0	0	0	3
JRC European Soil License Agreement	1	0	0	0	0	0	1	1	0	3
EEA standard re-use policy	1	0	0	0	1	0	0	0	0	2
Open data EU directive	0	0	0	0	0	1	0	0	0	1
CC BY	0	0	0	5	0	0	0	18	0	23
CC-BY-SA	1	0	0	0	0	0	0	0	0	1
ODbL	0	0	0	0	2	0	0	0	0	2
Etalab	0	0	0	0	5	0	0	0	0	5
Not Defined	2	0	0	0	1	3	21	0	44	71

With respect to the reported open-access licenses in the nine respective demos, we can indicate a diverse landscape in the adopted data-sharing and reuse policies. More specifically, DEMOs 1, 4, and 6 will benefit from the open-accessed LULC and High-Resolution Impervious Layer of the Land Monitoring Service of Copernicus, and the EU LUCAS soil library and thus should be committed to comply with the directions of the Copernicus Service commitments and license, JRC European Soil License agreement and the EEA standard re-use policy. All of the aforementioned licenses permit users to capitalize on the information provided, as well as to use and modify it for commercial purposes, with the prerequisite to officially acknowledge the data provider, as it is delegated by the Commission Delegated Regulation EU No 1159/2013 of 12 July 2013 (Copernicus.eu, 2021). A subsequent restriction is entailed by the Joint Research Center (JRC) prohibiting users from monetising these data sources by providing access to third parties.

An additional license that has been in favour of DEMOs 4 (83%) and 8 (95%) is the universal Creative Commons (CC) and in particular the “Attribution” licence, denoted as CC-BY. According to this license, users are permitted to use, distribute, remix, adapt and build upon the owner’s work even for commercial purposes, as long as they acknowledge the data owner for the original creation (Creative Commons, 2016). One interesting finding is that DEMO 8 have declared its intention to release the upcoming datasets under the CC-BY license, revealing a clear commitment of the consortium partners to openness and to further support future research. Two subsequent open-access licenses that solely have been adopted by DEMO 5 are the Open Data Commons Open Database License (ODbL) (22%) and the Etalab (56%), with the latest to be the only national bespoken licence that has been mentioned. With respect to ODbL, it is formulated with similar ethical guidelines as the one of CC Attribution and Share-Alike (CC-BY-SA) for Data/Databases (opendatacommons.org, n.d.), while the Etalab is characterised by the freedom to reuse information openly, freely and to reproduce, redistribute and adapt the initially generated information. It is compatible with the standards of the British Open Government License (OGL) and the international CC-BY (Etalab, n.d.).

Besides the aforementioned cases, unfortunately, the highest percentage (64 % in total) of the reported open datasets is not accompanied by a specific licence. Furthermore, DEMOs 2 and 3 stand out with the complete absence of open datasets, reflecting a minimal intention to adopt an open-access perspective. This significant lack of open-access licencing in all demos of the project poses noteworthy implications for the broader goals of the project and the EU to invest in open datasets. This uncertainty further undermines the principles of FAIR data, which are essential for scientific open research and achieving a high impact in EU-funded research projects. Thus, it is suggested to address these challenges as the project evolves and enforce the adoption of open-access policies to maximise data accessibility, the outreach of the project’s findings and compliance with EU general guidelines.

6 Deployment of Data Collection Strategy Methodology

The following sections provide detailed integration plans developed for each demo of CARDIMED project, with respect to the different data formats and accessibility interfaces and communication protocols that is expected to be adopted by each sub-demo. This will provide key information to T4.4 (Data orchestration module) but also to WP6 (T6.1) supporting the selection of appropriate instrumentation systems considering the proposed data acquisition mechanisms.

6.1 Data Integration Plan for DEMO1

6.1.1 In-situ Data

The data collection strategy for in-situ data collected at Lesbos, Mykonos, and Sifnos sub-demos follows an approach to ensure that data from various sensors is transmitted to the CARDIMED Middleware. In each site, a different method will be applied based on the types of sensors and the deployment strategy that already has been followed for existing sensors.

SubDemo 1.1: Lesbos

The IoT system of Lesbos, collects in-situ data through a network of weather stations, soil moisture sensors, flowmeters, and pressure sensors, which gather environmental data as described in Chapter 5.2.1. These sensors send their data to Programmable Logic Controllers (PLCs), which then transmit the data via TCP to a local server. On this server, a SCADA system processes the data received from the PLCs and stores it in a database for local use. To enable data transmission to the CARDIMED Middleware a local OPC to MQTT Client will be developed that will convert data from the SCADA system into MQTT message format. The CARDIMED Middleware will include an MQTT broker that receives data from this client allowing for internal storage directly or the triggering of ETL processes. This strategy is illustrated in Figure 57.

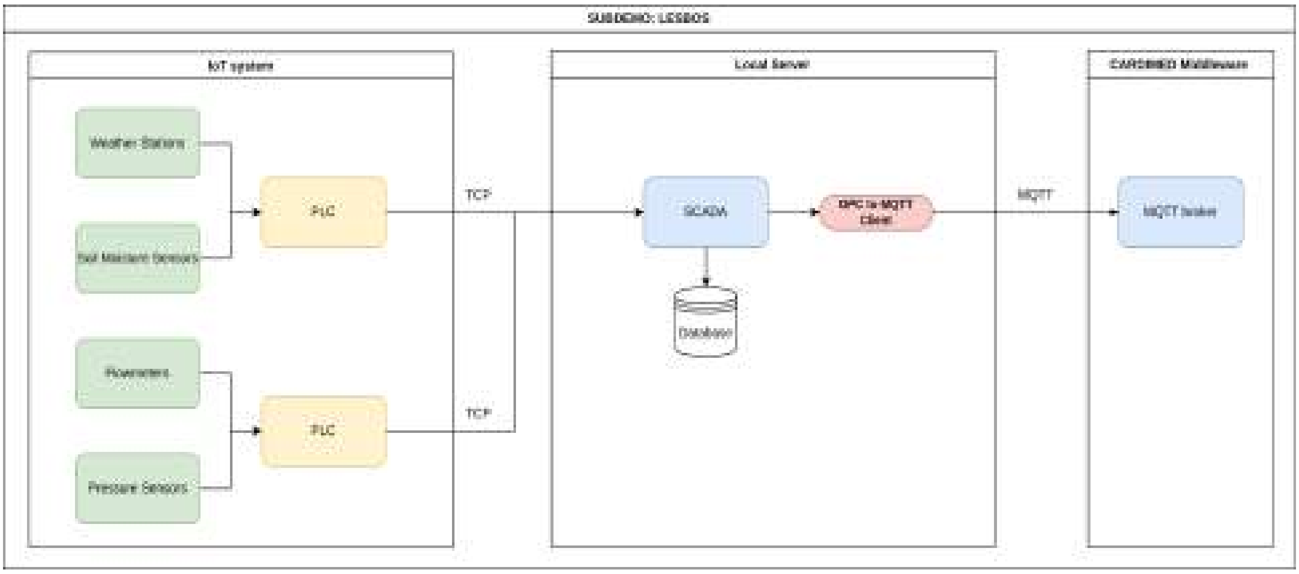


Figure 57: In-situ data collection strategy in Lesbos Subdemo

SubDemo 1.2: Mykonos

The Mykonos subdemo shares some common strategies with the Lesbos setup, particularly in the use of PLCs to collect data from sensors. This data is transmitted to a local server, where it is stored in a SCADA system and sent via an OPC to the MQTT Client to the CARDIMED Middleware's MQTT broker. This approach will be applied to water quality sensors, flowmeters, and water level sensors in HYDRO4 tanks.

Additionally, data from weather stations, soil moisture sensors, and water level sensors in HYDRO3 tanks are collected and stored in a third-party IoT platform provided by AGENSO, specifically the ardeusi.gr cloud platform. The data is stored in the cloud and is accessible through a public REST API endpoint, which has restricted access control. Permission must be granted to access this data. To collect this data, a REST client will be developed to consume data from the ardeusi.gr REST API, allowing for the ingestion of this sensor data into the CARDIMED Middleware. This strategy is illustrated in Figure 58.

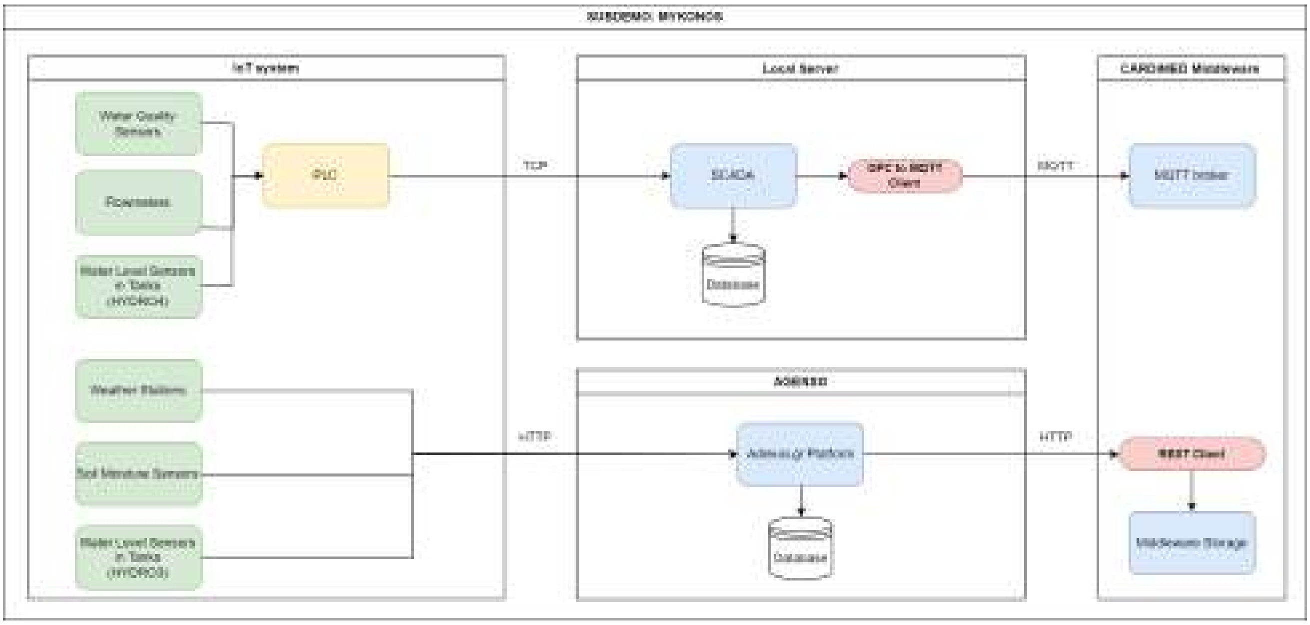


Figure 58: In-situ data collection strategy in Mykonos Subdemo

SubDemo 1.3: Sifnos

The IoT system for the Sifnos subdemo includes weather stations and water level sensors located in wells, and streams. Data from the weather stations is transmitted live to the METEO platform and stored in this third-party cloud storage. Although this data is not publicly available, it can be requested. To collect this data, a specific data ingestor will be developed to ingest this data into the CARDIMED Middleware.

Water level sensors in wells and streams provide both live and historical data. The historical data, which has a high temporal resolution, is stored internally on an onboard SD card in CSV format, while live data is transmitted via SMS as plain text messages and has a lower temporal resolution. To retrieve the live data and store it in Middleware, a dedicated SMS ingestor service will be developed. The historical data will be manually uploaded by the person responsible for collecting it from the field, using the graphical user interface of the Middleware’s file server. In this case, metadata may also be requested to be imported by the user to provide context, such as the sensor location or any other parameters that may be missing from the CSV dataset. This collection strategy is illustrated in Figure 59.

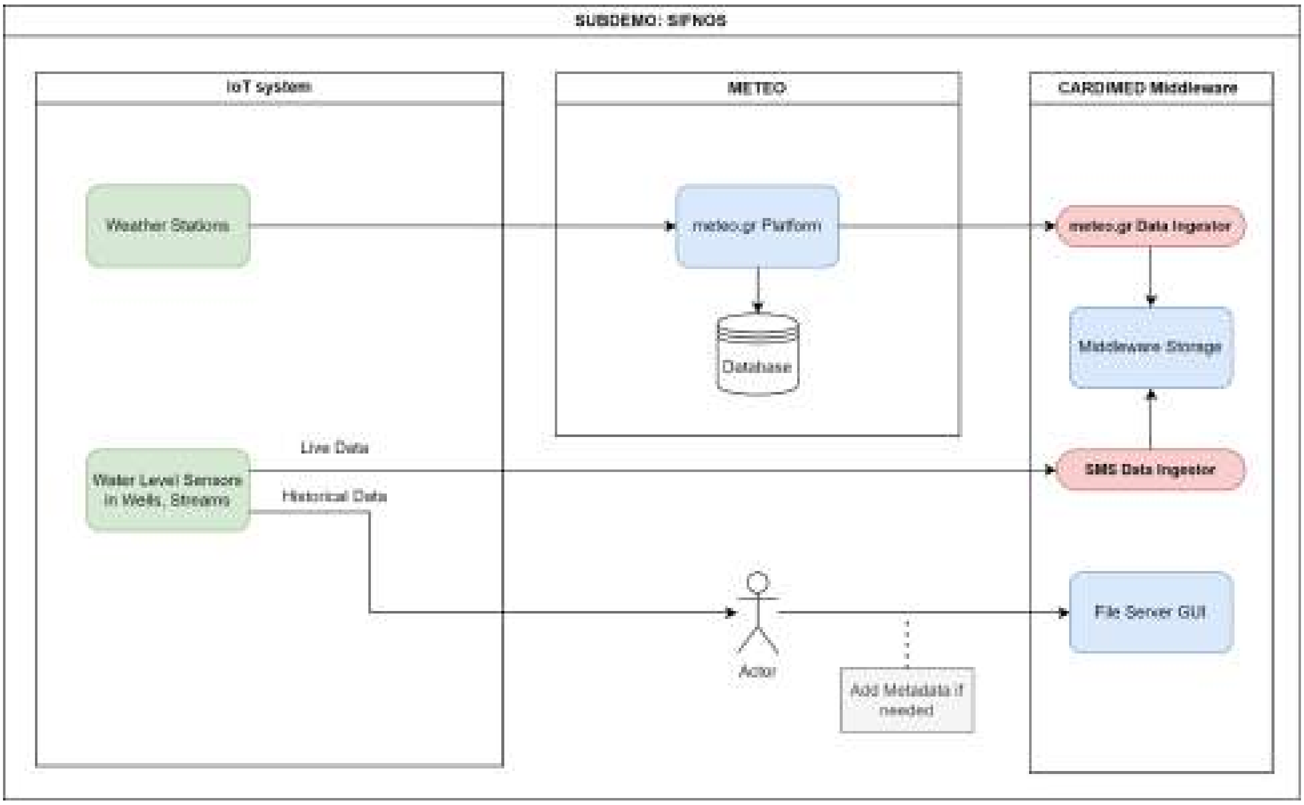


Figure 59: In-situ data collection strategy in Sifnos Subdemo

6.1.2 Laboratory Data

The laboratory data collection for both the Mykonos and Lesbos sub-demos follows the same strategy, while no such data exists for the Sifnos subdemo. This process includes water quality, chemical analysis, microbiological parameters, metals and ions, and various agricultural aspects. After the laboratory analysis is completed, a laboratory personnel member gathers the data and manually uploads it to the CARDIMED Middleware through the file server's graphical user interface. Additionally, metadata may need to be uploaded by the user to provide important context about the laboratory data. This strategy is illustrated in Figure 60, which includes the data collection processes for both subdemos.

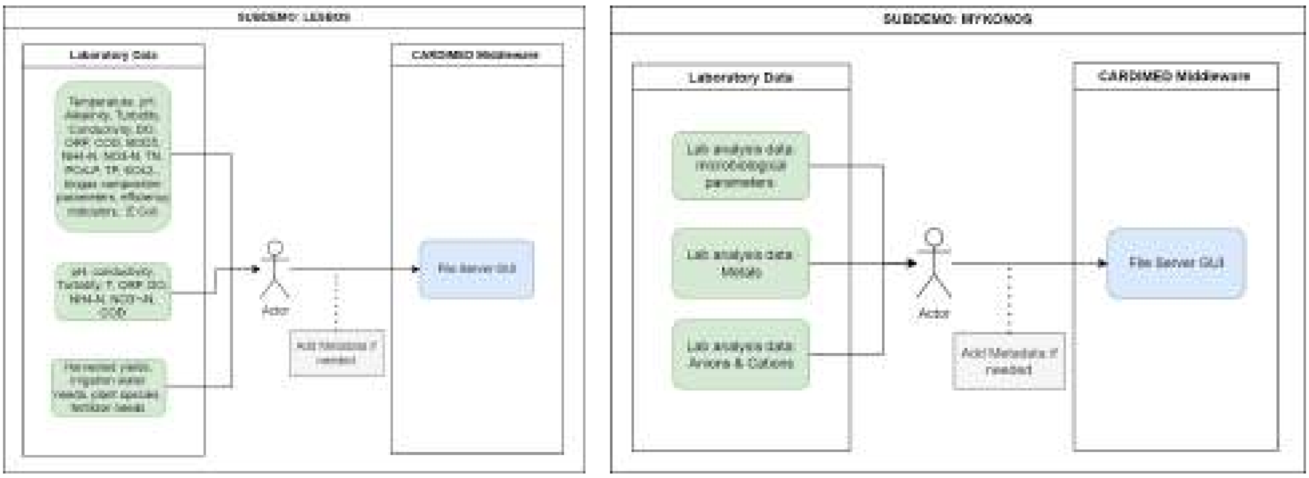


Figure 60: Laboratory data collection strategy in Lesbos and Mykonos Subdemos.

6.1.3 Unstructured data

Unstructured data, such as PDFs, need to be managed in the Sifnos subdemo, focusing on soil data from OPEKEPE and hydrolithological data from O.G.G. A person will be responsible for adding essential metadata to this unstructured data and ensure that it is transferred to the CARDIMED Middleware. The middleware will include a File Server GUI to facilitate this manual upload process, which is shown in Figure 61.

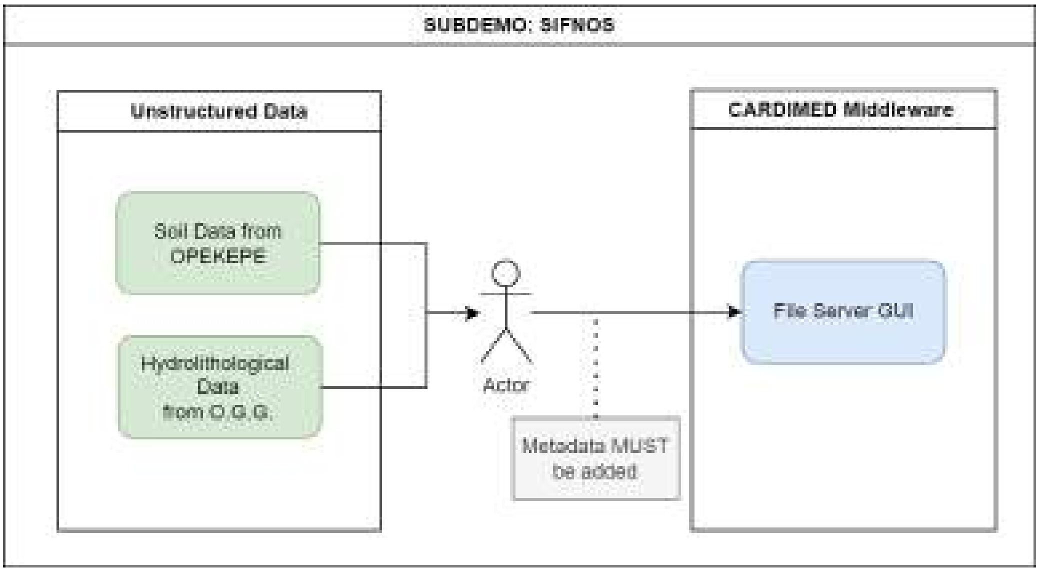


Figure 61: Unstructured data collection strategy for Sifnos Subdemo

6.1.4 Data from existing services and data platforms

The data collection strategy for existing services that are common to in the Sifnos, Lesbos, and Mykonos sub-demos involves integrating data from the European Environment Agency. This includes EUNIS ecosystem type maps, which cover habitat types, soil data, HANTS phenological data, potential natural vegetation, and elevation zones. The data can be accessed through either an ESRI REST Client or an OGC WMS Client, which need to be developed, to transfer this information into the CARDIMED Middleware. Once transferred, the data is stored in the middleware's storage system, ensuring it is available for analysis and application within the project. This process is illustrated in Figure 62.

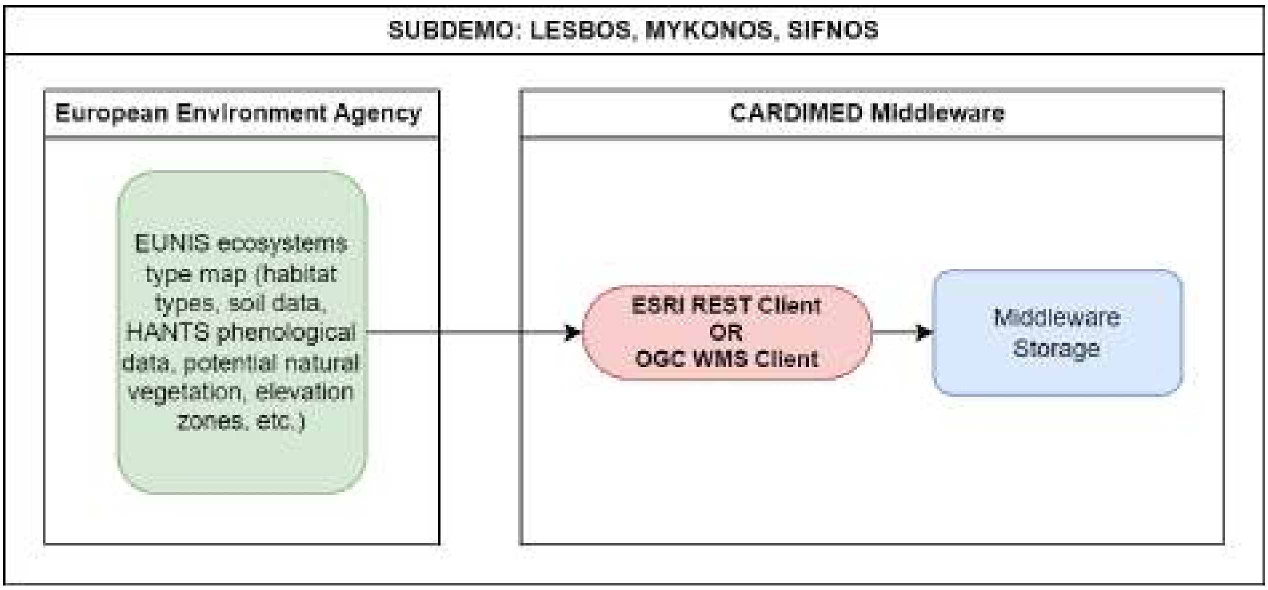


Figure 62: Data collection strategy from EUNIS platform for all subdemos

For the Sifnos subdemo specifically, additional data from various services need to be integrated into the CARDIMED Middleware. This includes data from the European Soil Data Center, such as the European Soil Database, Soil Bulk Density in Europe, GloREDa, and Topsoil physical properties. The Ministry for Environment and Energy provides Natura 2000 data, intensity-duration-frequency curves for precipitation, and hydrolithological data. Additionally, geological maps are sourced from the Hellenic Geological and Mining Research Authority. This data is ingested once using WMS or WFS clients, or through manual downloads from the data platform, and stored in the middleware as shown in Figure 63.

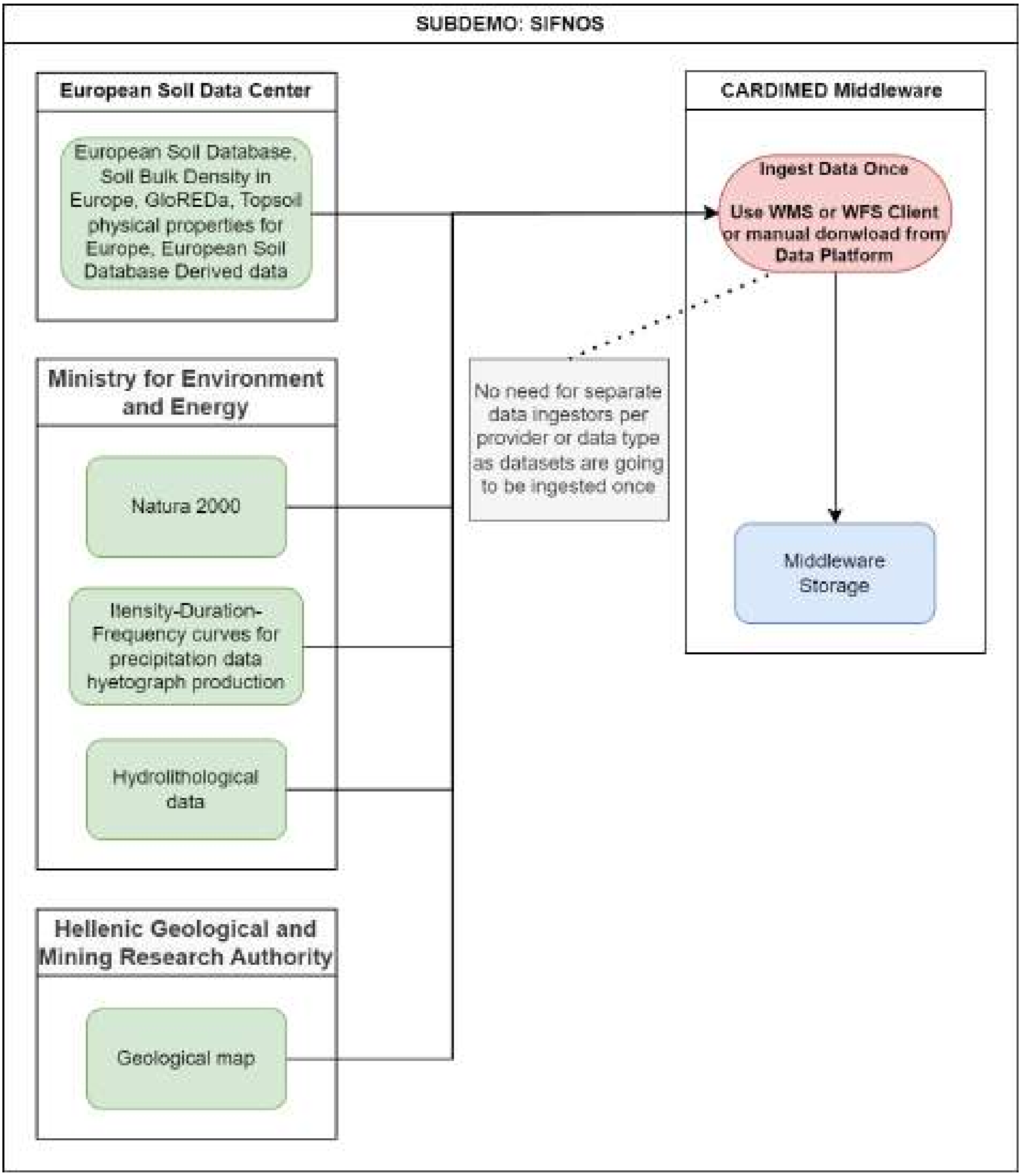


Figure 63: Data collection strategy from existing services and platforms that are related to Sifnos Subdemo

6.1.5 Earth Observation Data

The EO data strategy is related only to the Sifnos subdemo and involves integrating various datasets through the ICCS EO Platform that will be developed. This includes National Cadastral agency data for Digital Terrain Maps at 5m resolution, high-resolution DEMs using UAVs, and Copernicus CORINE Land Cover data. The data will undergo an ETL process and will become available for ingestion through the EO Platform's STAC API. It can then be accessed by CARDIMED Middleware using a STAC REST Client and made available to other project software components. This strategy is depicted in Figure 64.

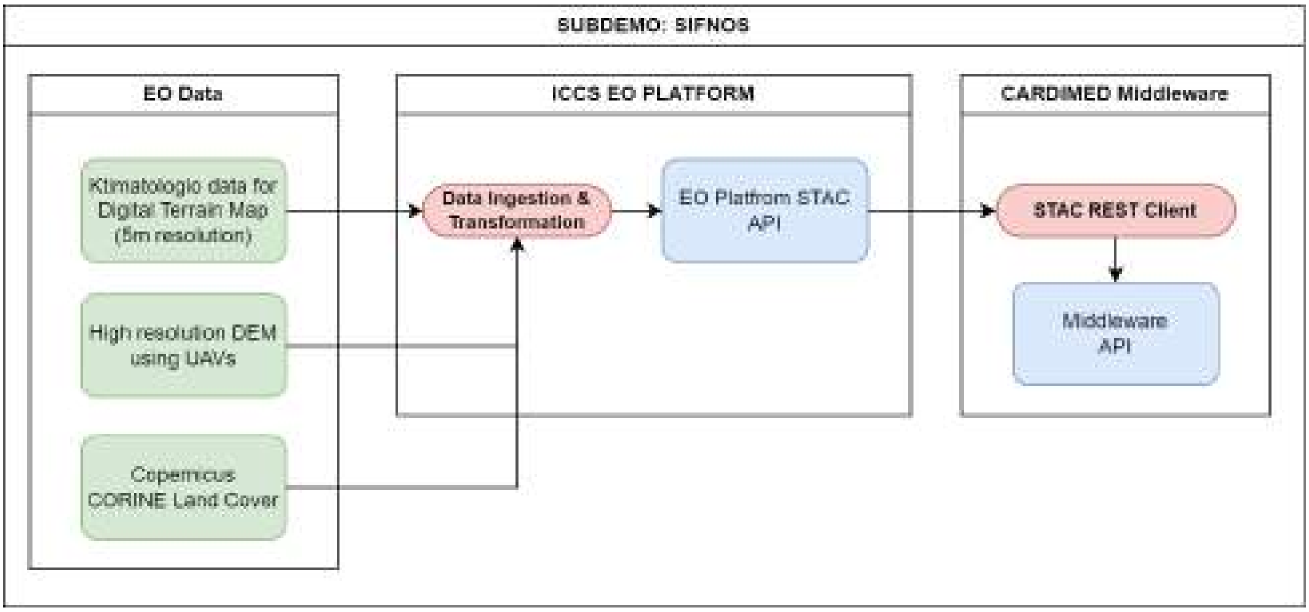


Figure 64: EO data collection strategy for Sifnos sub-demo

6.2 Data Integration Plan for DEMO2

6.2.1 In-situ Data

The in-situ data strategy for Demo 2 in HALCOR involves an IoT system that consists of various sensors. Specifically, water level sensors, pH sensors, conductivity sensors and temperature sensors connect to a PLC for data transmission. The data is then processed by a SCADA system on a local server, which stores it in a database. To retrieve the data from the SCADA system, an edge device will be deployed on the HALCOR premises. This edge device will ingest the data using an OPC client and transmit it to the CARDIMED Middleware, where it will be stored. Additionally, this edge device will collect data directly from the weather stations installed on the HALCOR premises and transmit them in the same way. Furthermore, data from the Hellenic National Meteorological Service (HNMS) weather stations will be integrated via the HNMS Platform, using a dedicated HNMS Data Ingestor that will send the data into the middleware. Figure 65 shows all these data flows.

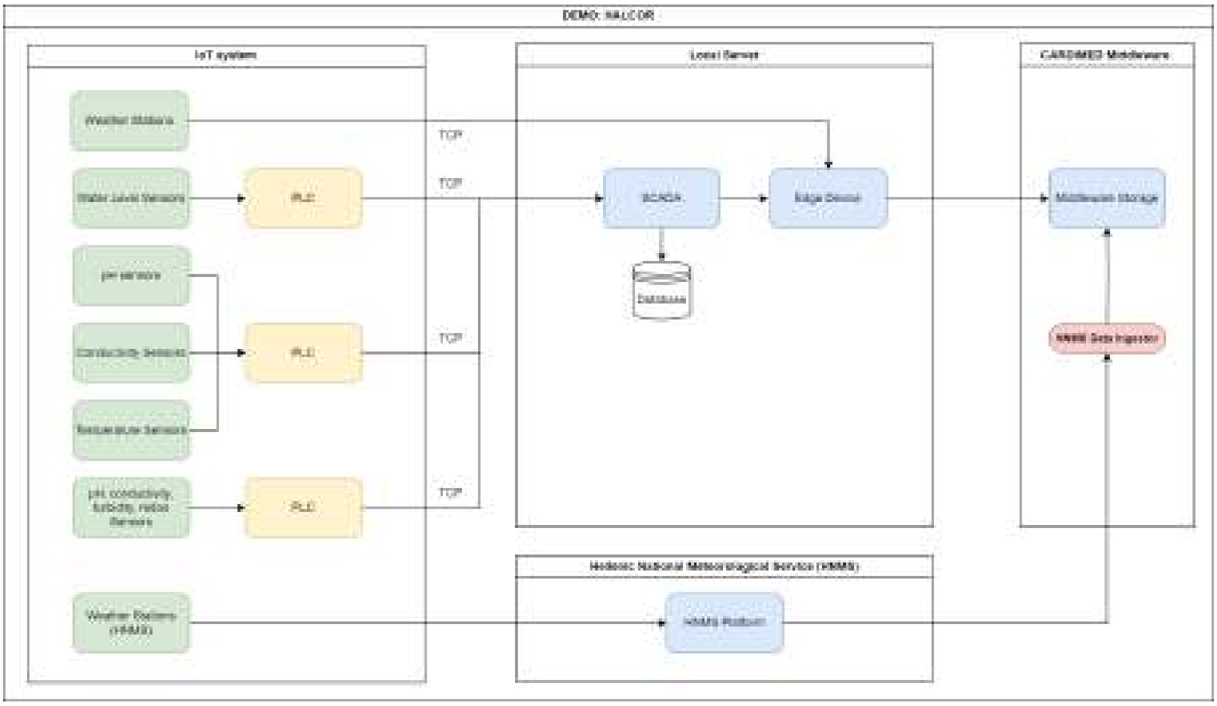


Figure 65: In situ data collection strategy for Halcor Demo

6.2.2 Laboratory Data

The laboratory data strategy for the HALCOR demo involves managing various lab analysis datasets, including microbiological parameters, metals, anions and cations, and heavy metals concentrations. A person will be responsible for ensuring that this data is properly prepared and, if necessary, adding metadata before it is uploaded. The data is then transferred to the CARDIMED Middleware using the File Server GUI, as shown in Figure 66.

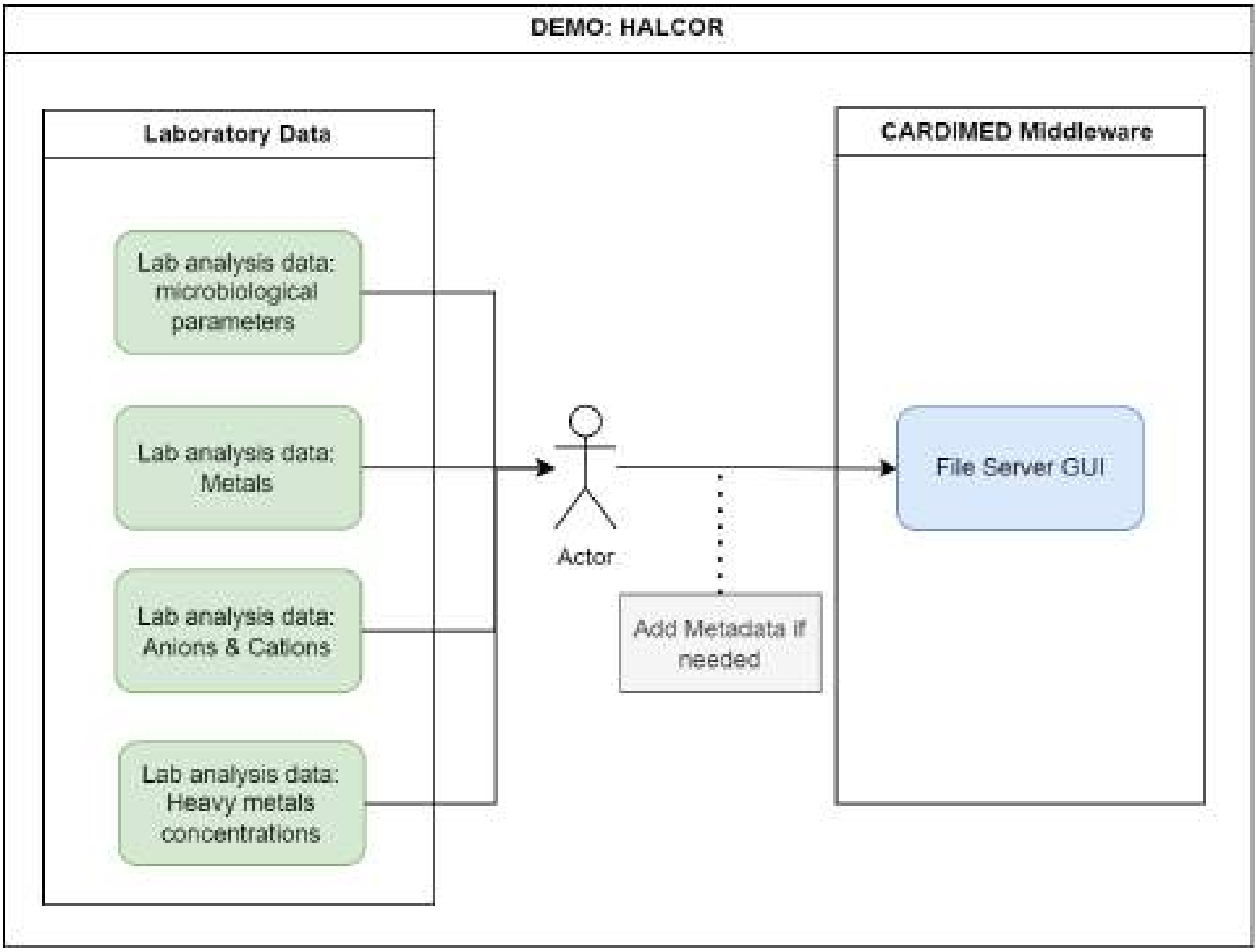


Figure 66: Laboratory data collection strategy for Halcor Demo

6.3 Data Integration Plan for DEMO3

6.3.1 In-situ Data

The data collection strategy for the IoT system of the Alghero and Calich Lagoon demo involves sensors supporting various protocols. Measurement devices, including pH, temperature, conductivity, fluorescence, and absorbance are connected to a PLC via the Hach protocol. The data is then transmitted from the PLCs to a local server using the Profinet protocol and is stored locally. Additionally, data from flowmeters and dissolved oxygen probes is collected from SD cards and USB devices, respectively using the Hanna proprietary protocol, while data from the par probe is transmitted to a mobile device through Bluetooth protocol. Manual data collection is also employed for temperature sensors, groundwater levels, and nutrient sensors (NH4, NO2, NO3). Throughout the process, all this data can be uploaded to the CARDIMED middleware by using the file server GUI, adding necessary metadata to provide context for the collected data. Figure 67 illustrates this data collection strategy highlighting the sensors, protocols and the data flow to the CARDIMED middleware.

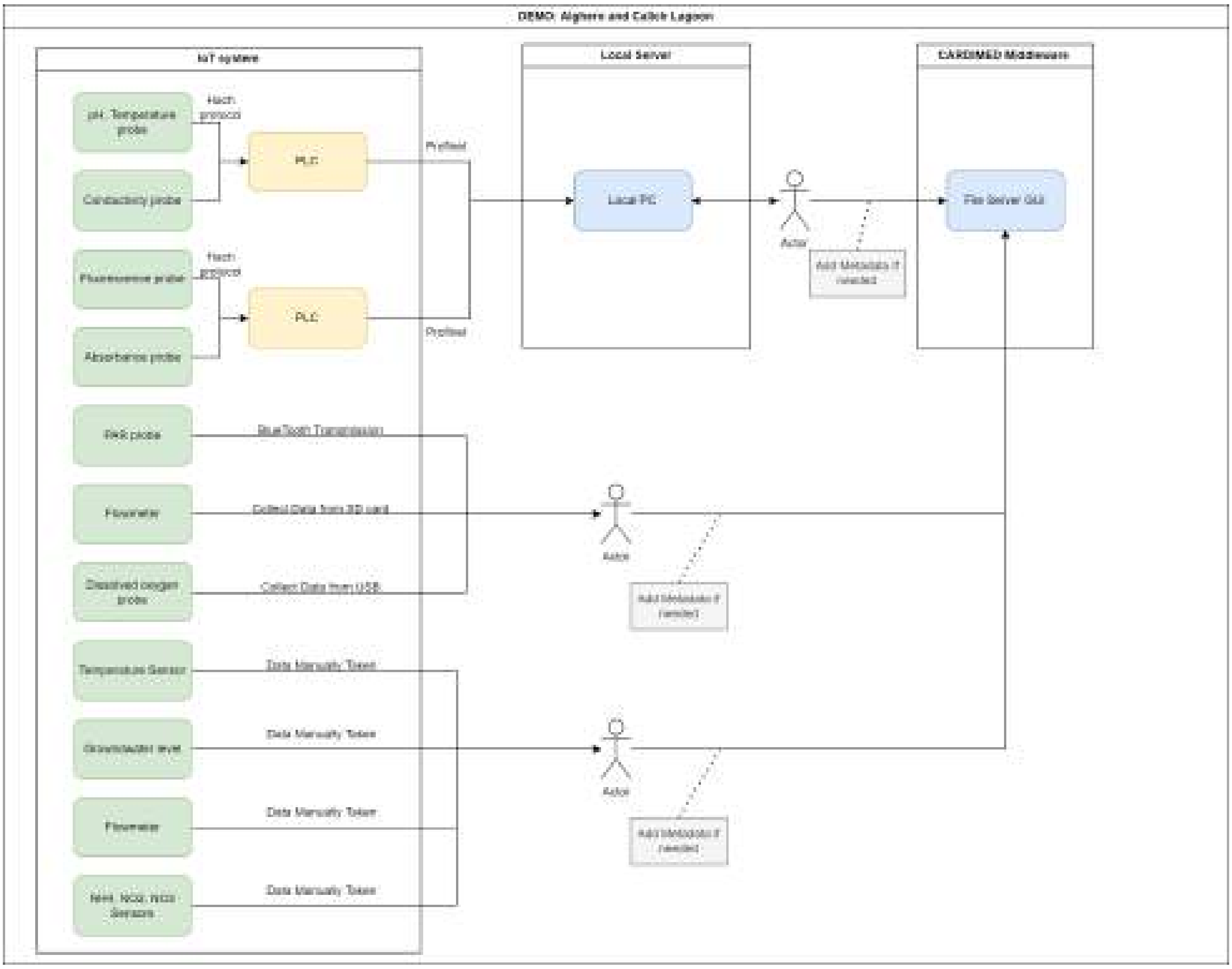


Figure 67: In situ data collection strategy for Alghero and Calich Lagoon

6.3.2 Laboratory Data

The laboratory data collection strategy in DEMO 3 focuses on soil, fish, and aqua environmental sampling. The analysis from soil sampling various chemical and physical attributes, including salinity, organic content, and contaminants are measured. From fish sampling, physiological responses are analysed related to environmental stressors, while aqua environmental sampling investigates the presence of aquatic flora and fauna through environmental DNA analysis. All this data with all relevant metadata needed is uploaded to the CARDIMED middleware manually by a person that has access to this laboratory analysis, as shown in Figure 68.

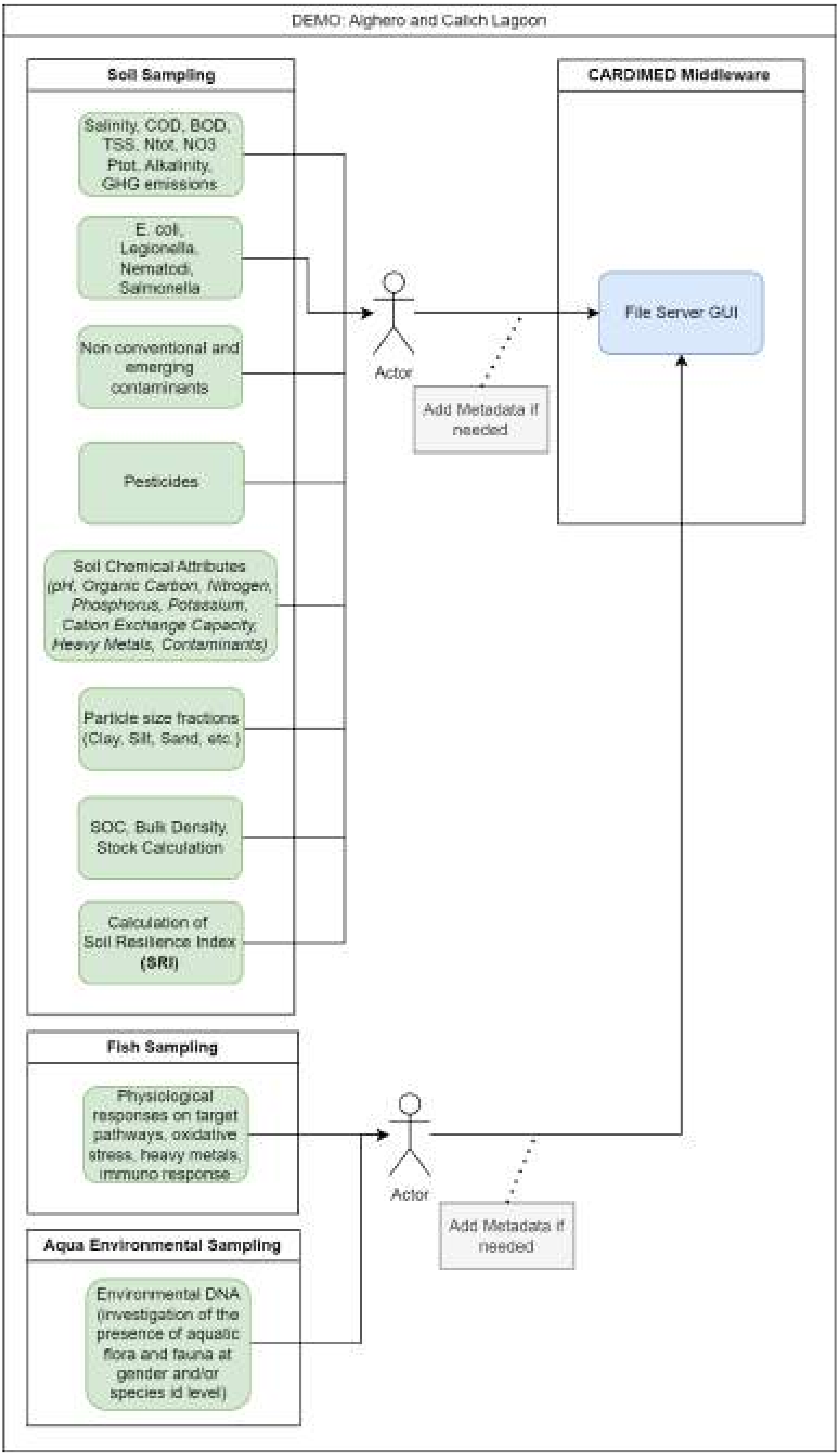

DEMO: Alghero and Calich Lagoon
Soil Sampling
Salinity, COD, BOD, TSS, Ntot, NO3 Ptot, Alkalinity, GHG emissions
E. coli, Legionella, Nematodi, Salmonella
Non conventional and emerging contaminants
Pesticides
Soil Chemical Attributes (pH, Organic Carbon, Nitrogen, Phosphorus, Potassium, Cation Exchange Capacity, Heavy Metals, Contaminants)
Particle size fractions (Clay, Silt, Sand, etc.)
SOC, Bulk Density, Stock Calculation
Calculation of Soil Resilience Index (SRI)
Actor
Add Metadata if needed
CARDIMED Middleware
File Server GUI
Fish Sampling
Physiological responses on target pathways, oxidative stress, heavy metals, immuno response
Actor
Add Metadata if needed
Aqua Environmental Sampling
Environmental DNA (investigation of the presence of aquatic flora and fauna at gender and/or species id level)

Figure 68: Laboratory data collection strategy for Alghero and Calich Lagoon

6.4 Data Integration Plan for DEMO4

6.4.1 In-situ Data

The data collection strategy for in-situ data collected at the Rain Garden in Catania and Green Wall of Feria involves an approach to ensure that data from sensors is transmitted to the CARDIMED Middleware. In each site, a different method is applied based on the types of sensors and the deployment strategy that already has been followed for existing sensors.

SubDemo 4.1: Rain Garden in Catania

The in-situ data strategy for the Rain Garden in Catania involves using weather stations as part of the IoT system. A person responsible for managing the data can transfer them to the CARDIMED Middleware via a File Server GUI. Any necessary metadata can be added during this process if needed to add context about the collected dataset as shown in Figure 69.

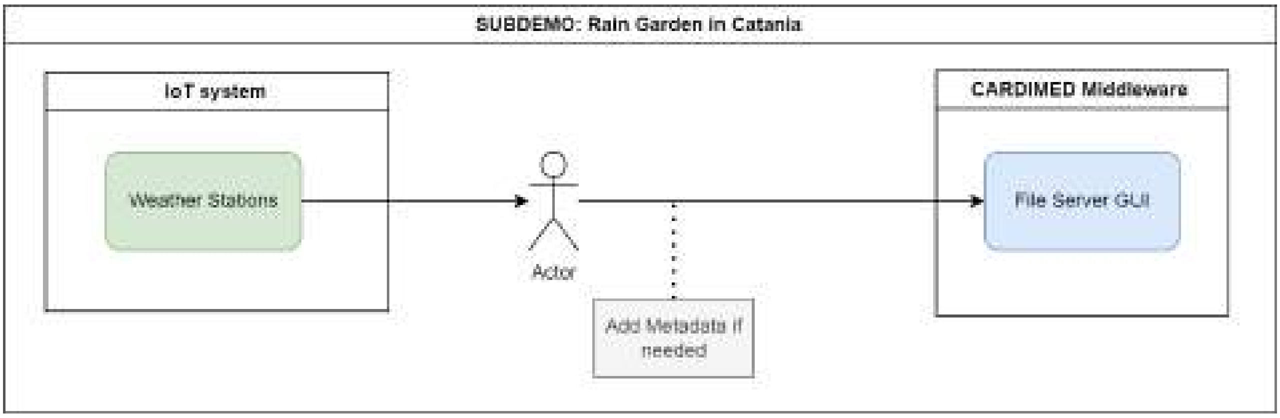


Figure 69: In situ data collection strategy of Rain Garden in Catania

SubDemo 4.2: Green Wall of Feria

The data collection strategy for the Green Wall of Feria involves an IoT system with Agronic air temperature sensors and flowmeters. Data is transmitted via local WiFi or GPRS network to the third-party Agronic Platform, where it is stored in a database. This data can be transferred to CARDIMED Middleware using a REST Client that needs to be developed and then can be stored internally as shown in Figure 70.

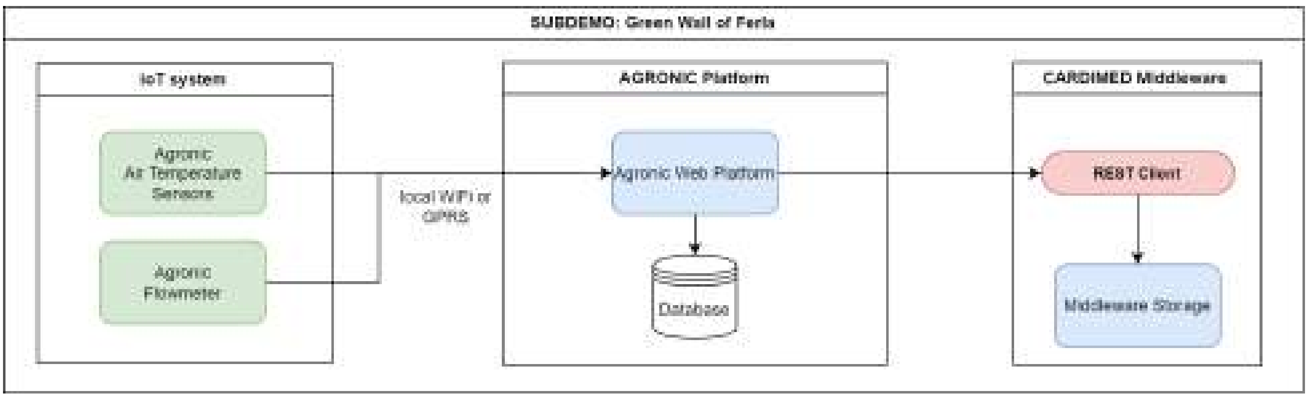


Figure 70: In situ data collection strategy of Green Wall of Feria

6.4.2 Laboratory Data

The strategy for integrating laboratory data of DEMO 4 into the CARDIMED Middleware is common across both the Rain Garden in Catania and the Green Wall of Feria. While there are common parameters in the data collected during this analysis at each site, some specific differences exist.

Both the Rain Garden in Catania and the Green Wall of Feria share common laboratory analysis data, including conductivity, pH, total suspended solids (TSS), chemical oxygen demand (COD), total nitrogen (Ntot), and total phosphorus (Ptot). These parameters are crucial for assessing water quality and environmental health. However, the Rain Garden in Catania also measures flow, volume, moisture, or level, which are specific to its environmental monitoring needs. The integration of these data laboratory data for sub-demos into the CARDIMED Middleware can be done through the File Server GUI, where the person that uploads them, ensures that all necessary metadata is added. This process is shown in Figure 71.

Figure 71: Laboratory data collection strategy of Rain Garden in Catania (left) and Green Wall of Feria (right)

6.4.3 Unstructured Data

Unstructured data is collected for this demo only for the case of Rain Garden in Catania and it involves capturing pictures for visual evaluation of plant status using a mobile device. These images can then be manually uploaded to the CARDIMED Middleware via a File Server GUI, and any metadata needed can be added at this stage as shown in Figure 72.

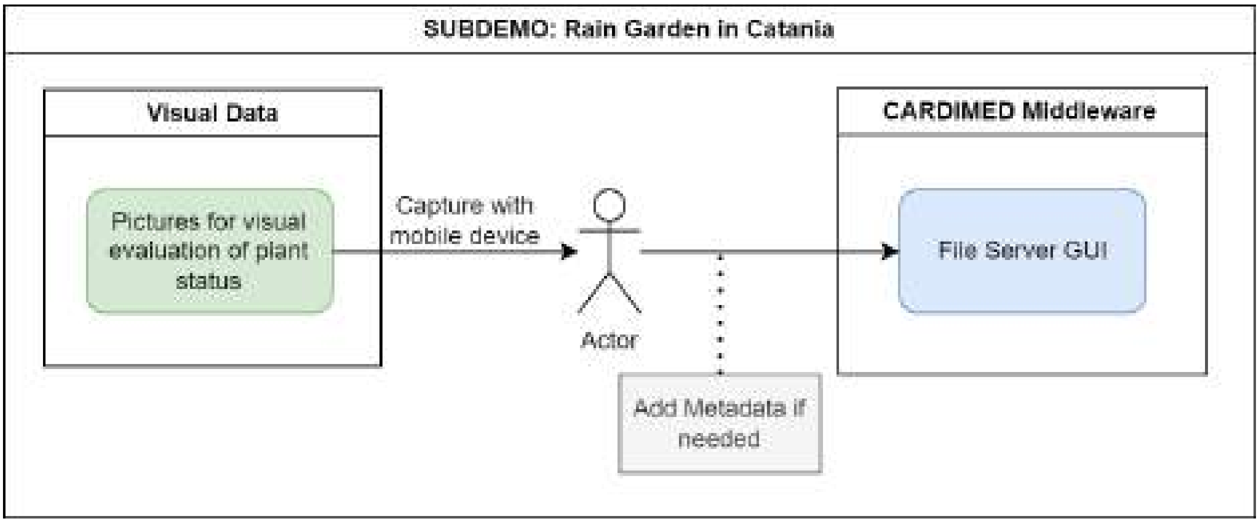


Figure 72: Visual Data collection from Rain Garden in Catania subdemo.

6.4.4 Data from existing Services and Data Platforms

The data integration strategy for the Rain Garden in Catania and the Green Wall of Feria also involves existing services and data platforms. Such data is from the Servizio Informativo Agrometeorologico Siciliano, which is related to weather station measurements. Additionally, the Civil Protection Department of Sicily Region provides data on road infrastructure, hydrography, geomorphology, vegetation, cadastral cartography, habitat, and ecological value. Orthophotos and digital terrain models are also included. This data can be ingested by using either WMS or WFS clients or through manual downloads and stored in the CARDIMED Middleware as shown in Figure 73.

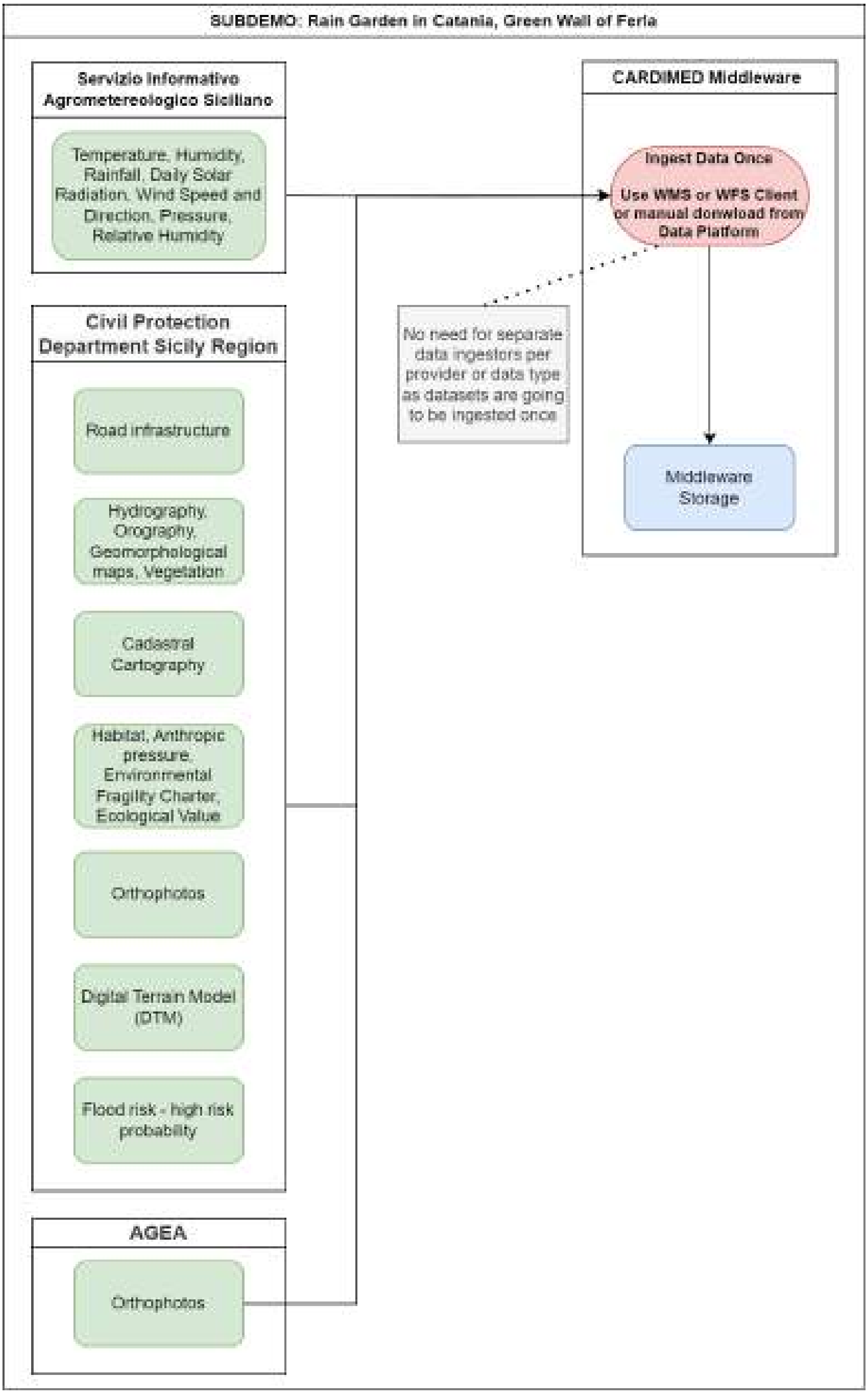


Figure 73: Data integration diagram of existing services and data platforms for both subdemos.

6.4.5 Copernicus Earth Observation Data

The Copernicus Earth Observation data strategy involves integrating Copernicus CORINE Land Cover data, for both Rain Garden in Catania and Green Wall of Feria, through the ICCS EO Platform that will be developed. The data will undergo an ETL process and will become available for ingestion through the EO Platform's STAC API. It can then be accessed by CARDIMED Middleware using a STAC REST Client as shown in Figure 74.

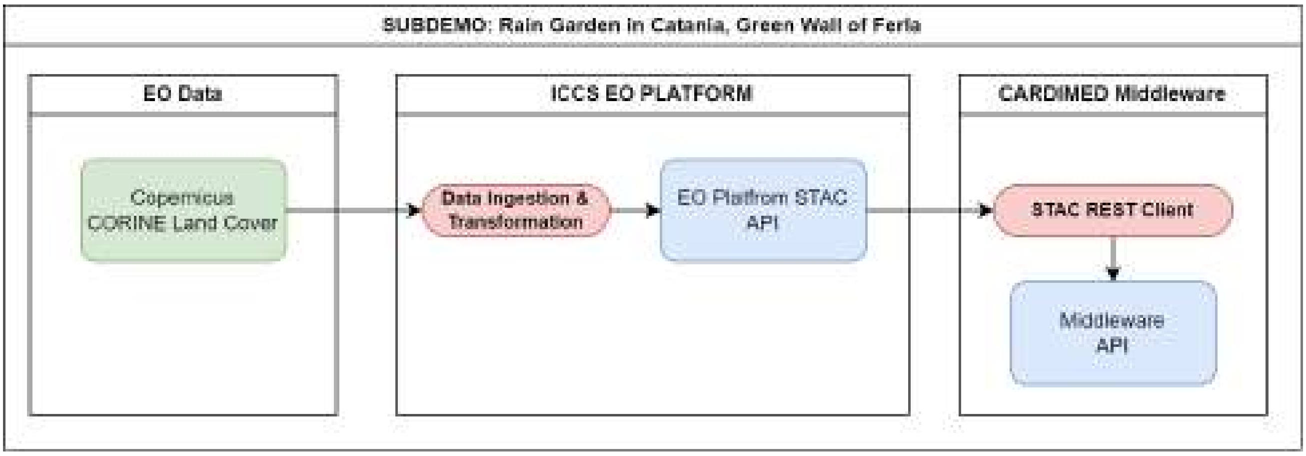


Figure 74: EO Integration plan for Rain Garden in Catania and Green Wall of Feria

6.5 Data Integration Plan for DEMO5

6.5.1 In-situ Data

The in-situ data section for this demo involves collecting various types of data across two subdemos, Saint Charles and Saint Jérôme. Some data is specific to each subdemo, while other data is shared between both. For clarity, the common data sources will be described first, followed by the additional data specific to each subdemo.

Common data sources include a variety of environmental sensors collected by different providers. Data from temperature and air quality sensors, as well as citizen microsensors, are collected and stored by the third-party platform AtmoSud. Additionally, data from citizen NetAtmo sensors are collected and stored by the third-party platform NetAtmo. To ingest this data into the CARDIMED middleware, access to both the AtmoSud and NetAtmo platforms must be granted, and two dedicated data ingestors (one for each platform) need to be developed.

The Marseille Metropole platform collects and stores data from temperature and humidity sensors, as well as weather stations installed in the areas of interest for DEMO 5. To integrate this data into the CARDIMED middleware, a REST client needs to be developed to consume the platform's API and store the data in the middleware's storage.

Lastly, rainfall and runoff discharge measurements are sent to a dedicated server equipped with its own custom API. This data will be integrated into the middleware using a custom API ingestor, which needs to be developed to extract and store the data in the middleware's storage. This integration plan is depicted in Figure 75.

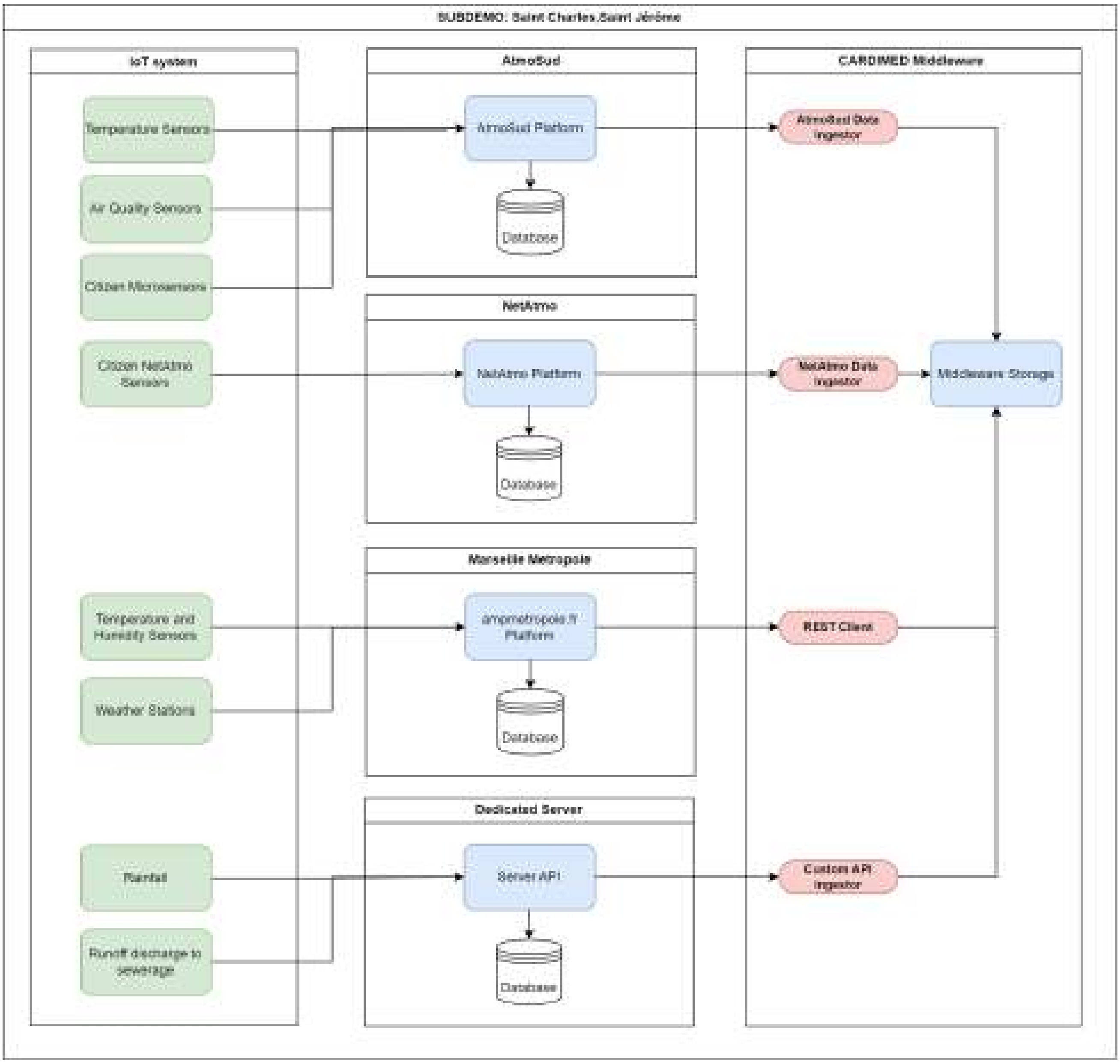


Figure 75: In situ common data integration plan for Saint Charles and Saint Jerome

SubDemo 5.1: Saint Jérôme

In the Saint Jérôme subdemo extra environmental data are collected, including electrical resistivity tomography (ERT), magnetism, spontaneous potential, soil pollutants, soil layer observations, soil carbon storage, soil permeability, water infiltration, weather conditions, air quality, and soil humidity. This data is transmitted to a dedicated server, where it is stored in a local database. A custom API ingestor that will be developed, extracts the data and transfers them to the CARDIMED Middleware as shown in Figure 76.

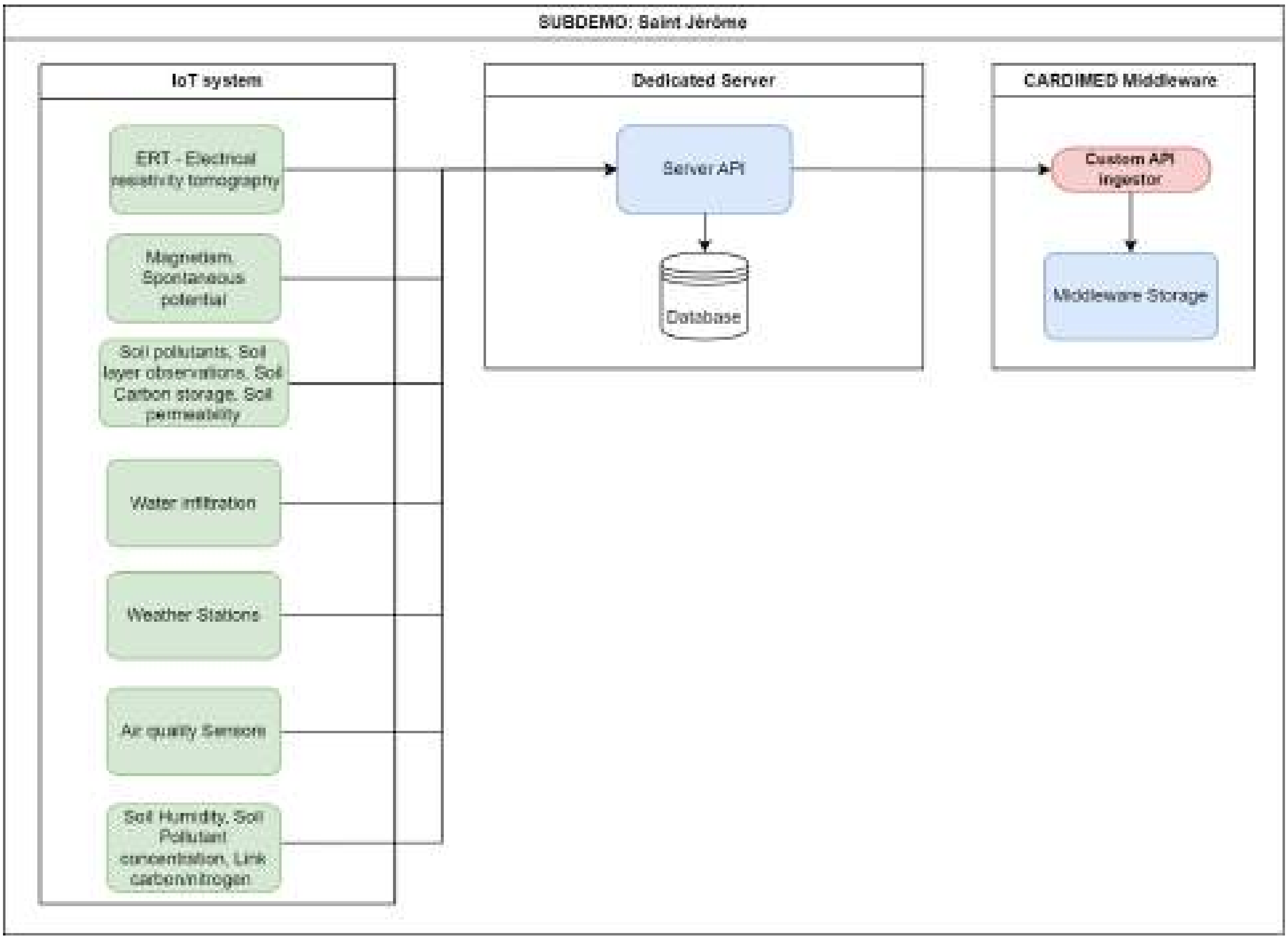


Figure 76: In-situ data integration plan for extra data sources of Saint Jérôme sub demo

SubDemo 5.2: Saint Charles

In the Saint Charles subdemo, the extra environmental data that are collected are related to groundwater temperature, conductivity, and height, as well as information from weather stations and air quality sensors. This data is transmitted to a dedicated server, where it is stored in a database. A custom API ingestor needs to be developed to transfer the data to the CARDIMED Middleware as shown in Figure 77.

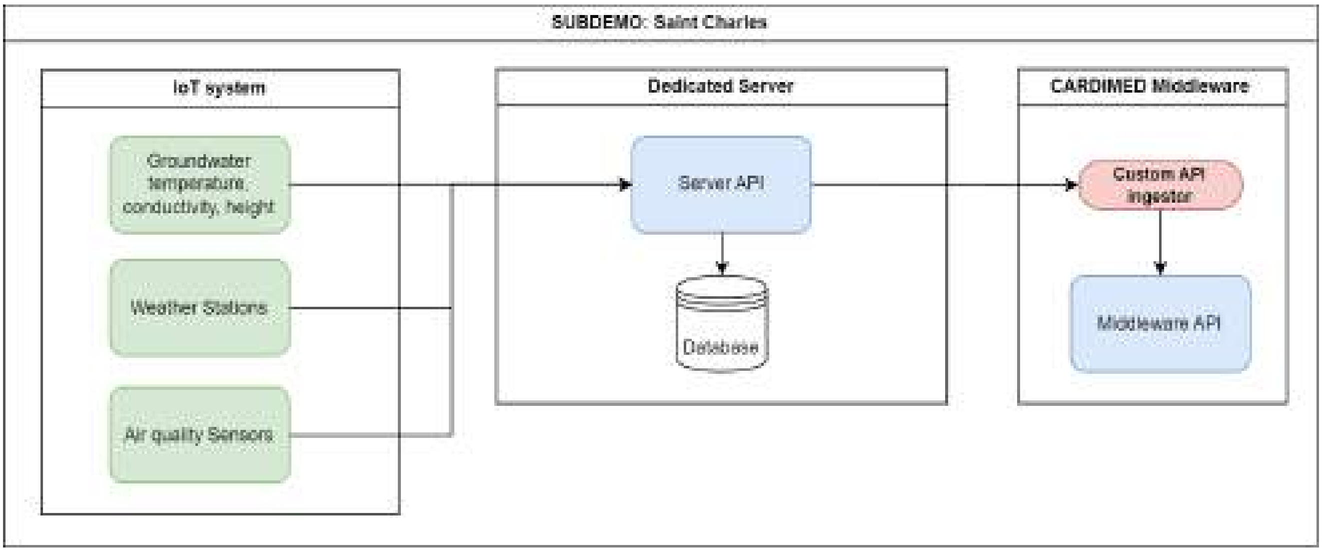


Figure 77: In-situ data integration plan for extra data sources of Saint Charles sub-demo

6.5.2 Unstructured Data

For both the Saint Charles and Saint Jérôme subdemos, unstructured data in the form of aerial photos are collected. These photos are provided by the French Government Geoservices and need to be integrated into the platform. Since this integration is a one-time process, there is no need to develop a dedicated service. The data can be retrieved and transferred to the middleware storage as shown in Figure 78.

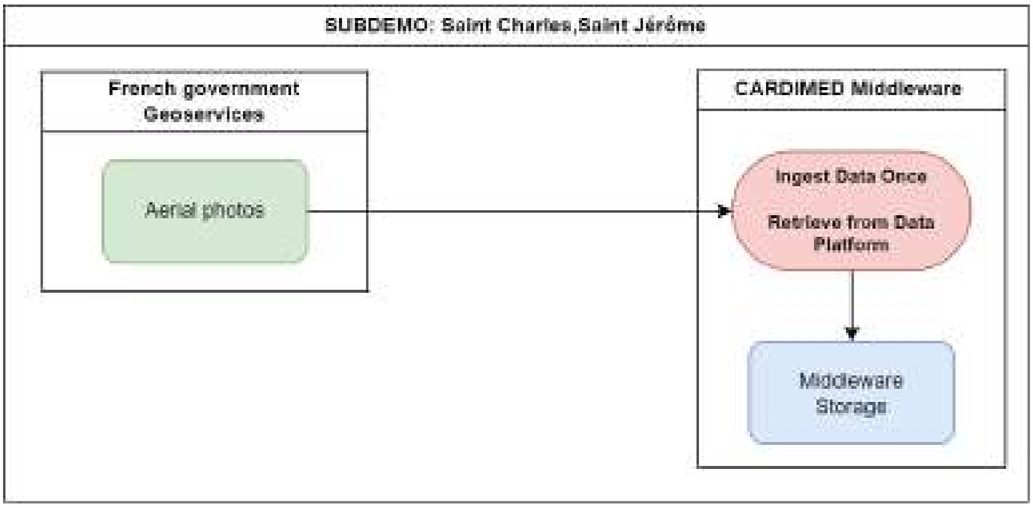


Figure 78: Unstructured data integration plan for both Saint Charles and Saint Jerome sub-demos

6.5.3 Structured Data from Custom Services

Various datasets from Aix-Marseille University that are related to both Saint Charles and Saint Jérôme subdemos are not currently provided by any existing service. This includes campus maps, LIDAR geographical layers, floral inventory, animal species data, and citizens' perception surveys. Additionally, for the Saint Jérôme subdemo, data from the University Institute of Industrial Thermal Systems and Aix-Marseille University is included, covering global sunshine (simulated data), mesofauna identification, mesofauna density, and insect identification. These datasets will be collected and stored on a dedicated server. A custom API ingestor will collect this data from the server API and then transfer it to CARDIMED Middleware as shown in Figure 79 and Figure 80.

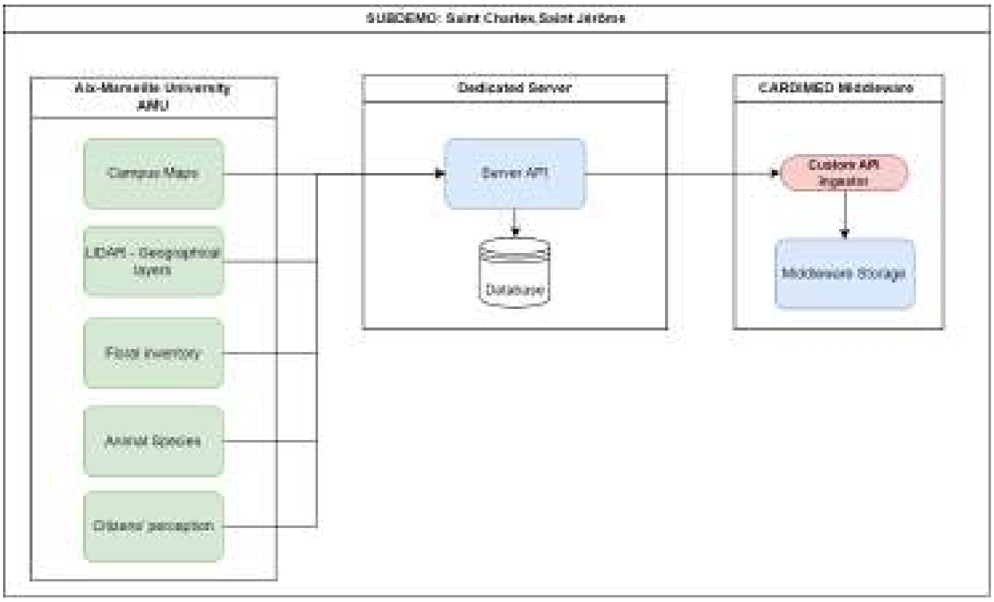


Figure 79: Data integration of structured data that are not provided by existing services for both Saint Charles and Saint Jerome

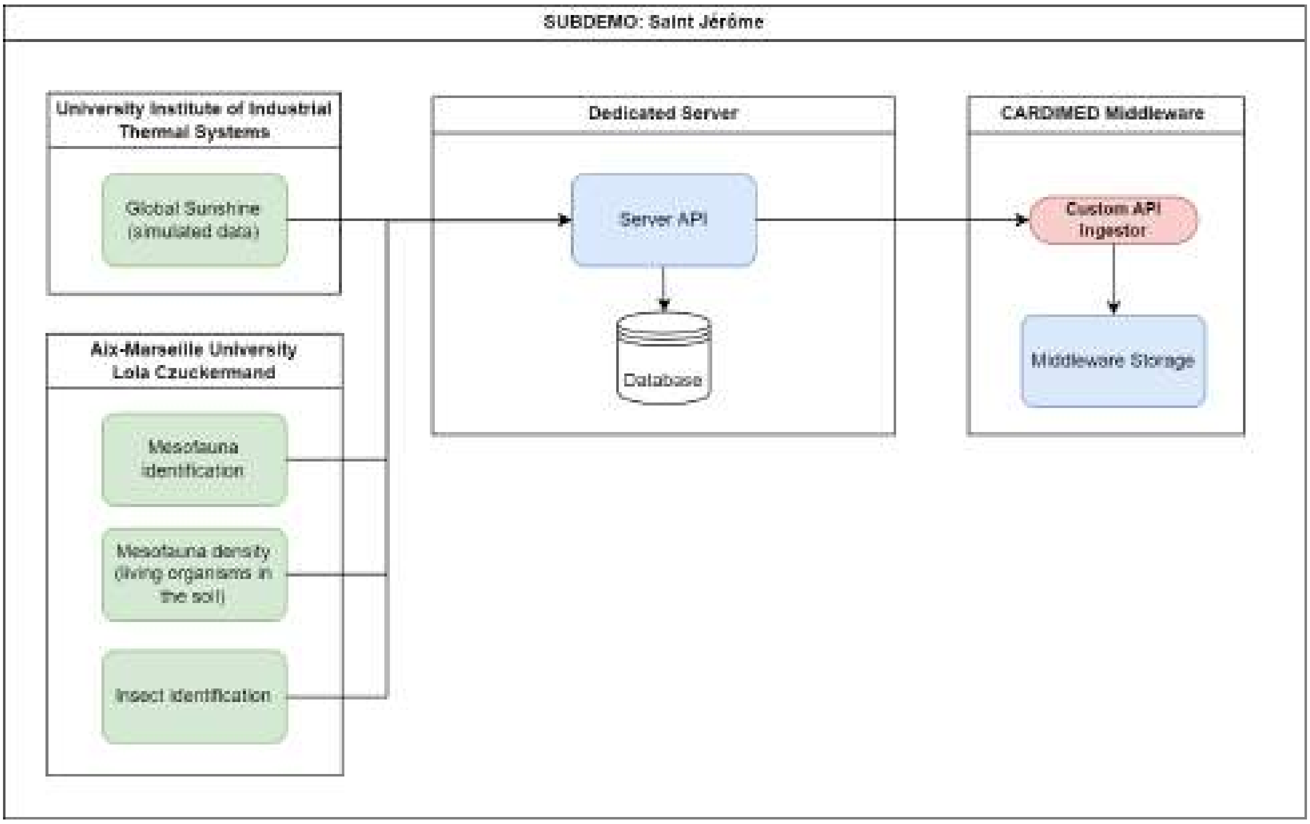


Figure 80: Data integration of structured data that are not provided by existing services for Saint Jerome

6.5.4 Data from existing Services and Data Platforms

An integration plan needs to be developed for existing datasets from various services and data platforms for both the Saint Charles and Saint Jérôme subdemos. These include parcel geospatial data from the French government's Geoportal, urban heat spots from the Marseille municipality's NEPSEN, and Local Climate Zones (LCZ) maps from the Marseille Metropole. Additionally, hydrologic reference projections can be sourced from Meteo France DRIAS, while land use data is provided by both Marseille Metropole and the Provence-Alpes-Côte d'Azur DATASUD Platform. These datasets can be ingested probably only once into the CARDIMED Middleware using WMS or WFS clients or through manual downloads as shown in Figure 81. The options for ingestion are related to the capabilities supported by the data platforms.

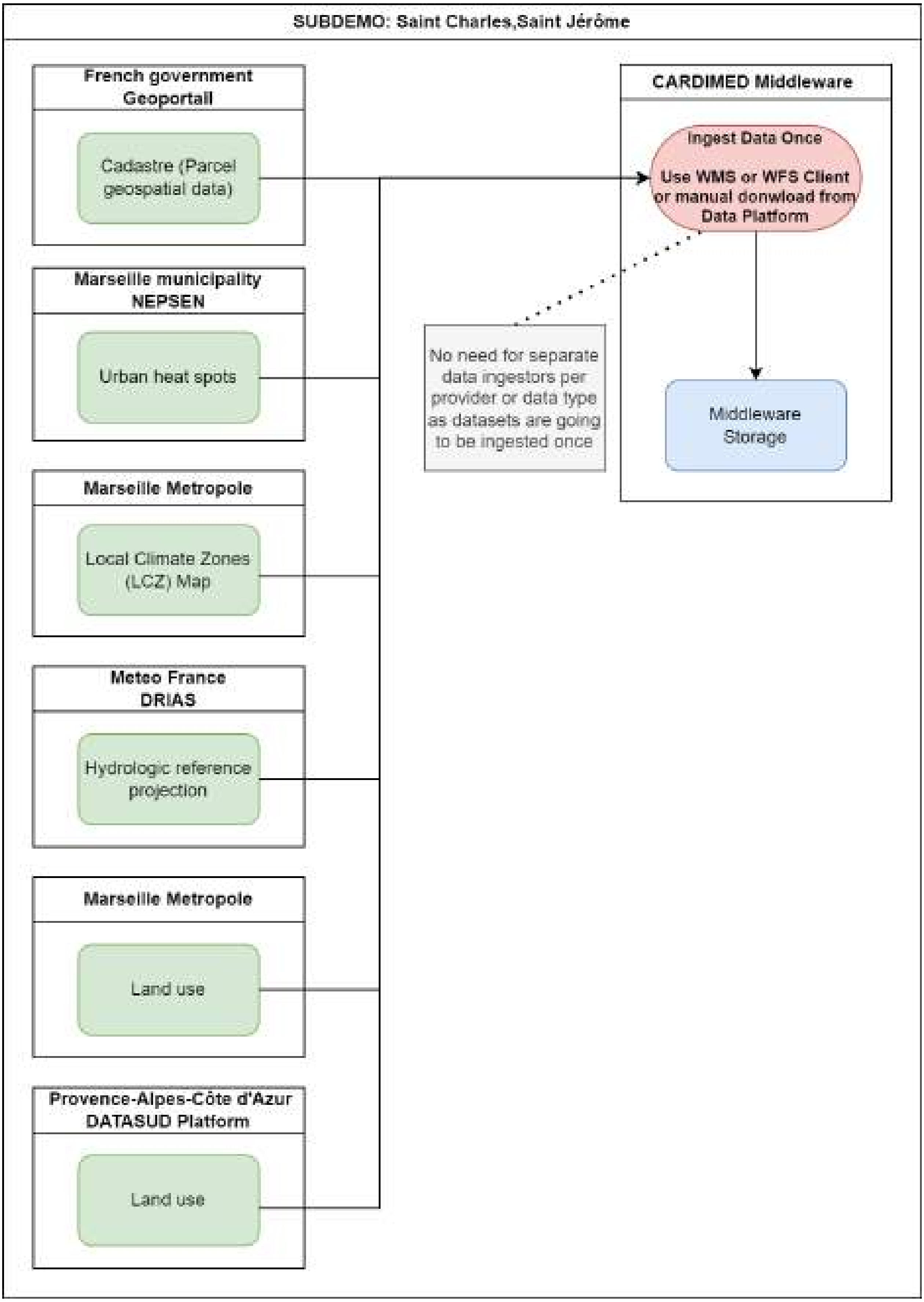

SUBDEMO: Saint Charles,Saint Jérôme
French government Geoportail
Cadastre (Parcel geospatial data)
Marseille municipality NEPSEN
Urban heat spots
Marseille Metropole
Local Climate Zones (LCZ) Map
Meteo France DRIAS
Hydrologic reference projection
Marseille Metropole
Land use
Provence-Alpes-Côte d'Azur DATASUD Platform
Land use
CARDIMED Middleware
Ingest Data Once
Use WMS or WFS Client or manual donwload from Data Platform
Middleware Storage
No need for separate data ingestors per provider or data type as datasets are going to be ingested once

Figure 81: Data integration diagram of existing services and data platforms for both subdemos

6.5.5 Copernicus Earth Observation Data

The Copernicus Earth Observation data strategy for the Saint Charles and Saint Jérôme sub-demos involves using the ICCS EO Platform to collect data from Copernicus (Figure 82). This includes the CORINE Land Cover and High-Resolution Layer Imperviousness datasets. The data will undergo ingestion and transformation on the ICCS EO Platform and will be served with STAC API and then transferred to CARDIMED Middleware via a STAC REST Client.

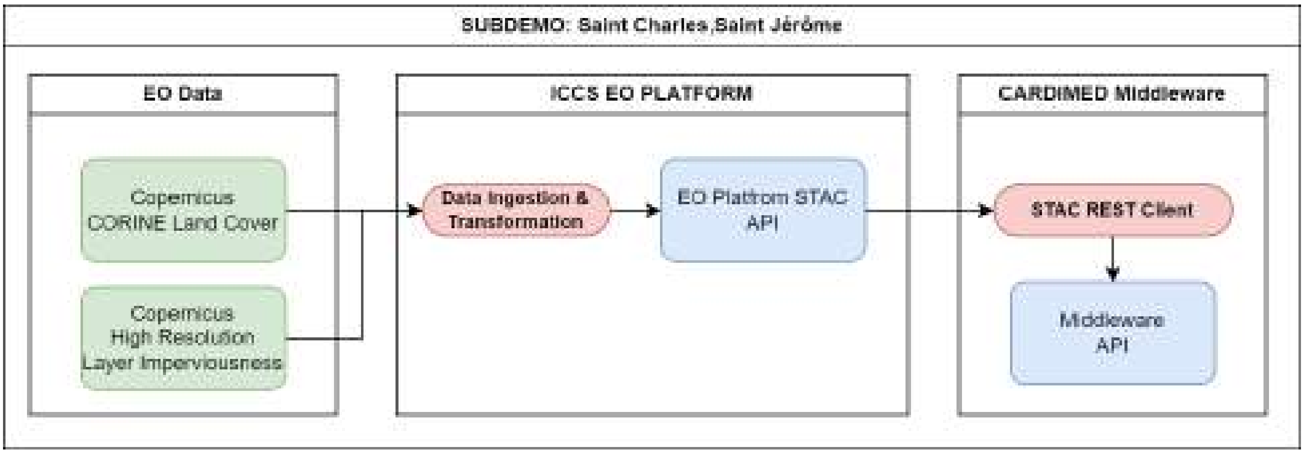


Figure 82: EO Data Integration diagram for sub-demos Saint Charles and Saint Jerome

6.6 Data Integration Plan for DEMO6

6.6.1 In-situ Data

The in-situ data integration plan for DEMO 6 involves an IoT system equipped with exterior and interior temperature and humidity sensors. These sensors transmit data to a LoRaWAN Gateway deployed near them, which then sends the data via UDP to a ChirpStack Gateway Bridge on a local server. This Bridge is responsible for extracting the payload from the LoRaWAN data model, transforming it into MQTT format, and transmitting it to a local MQTT broker. The ChirpStack service, which subscribes to relevant MQTT topics, stores this data in an internal database. To send the data to the CARDIMED Middleware, another MQTT client needs to be developed that retrieves the data from the database and transfers it to the middleware's MQTT broker located in the cloud as shown in Figure 83.

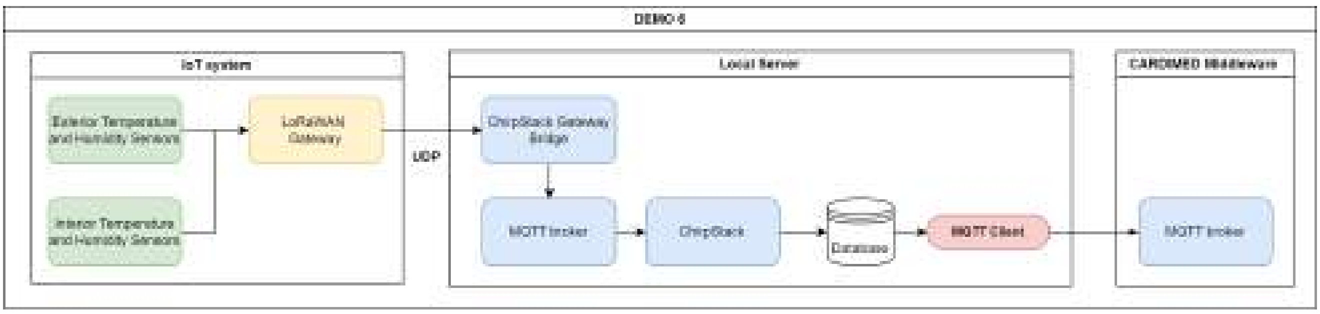


Figure 83: In-situ data integration diagram from sensors supporting LoRaWAN protocol.

6.6.2 Data from existing Services and Data Platforms

The data integration plan from existing services for DEMO 6 involves extracting solar radiation and wind data using the Copernicus Data Space API and AEMET API. This data is processed on a local server, where solar radiation and wind data are extracted from rasterized images and undergo ETL (Extract, Transform, Load) transformations. The transformed data is stored in a local database and then transferred to the CARDIMED Middleware MQTT Broker via an MQTT client deployed in the local server.

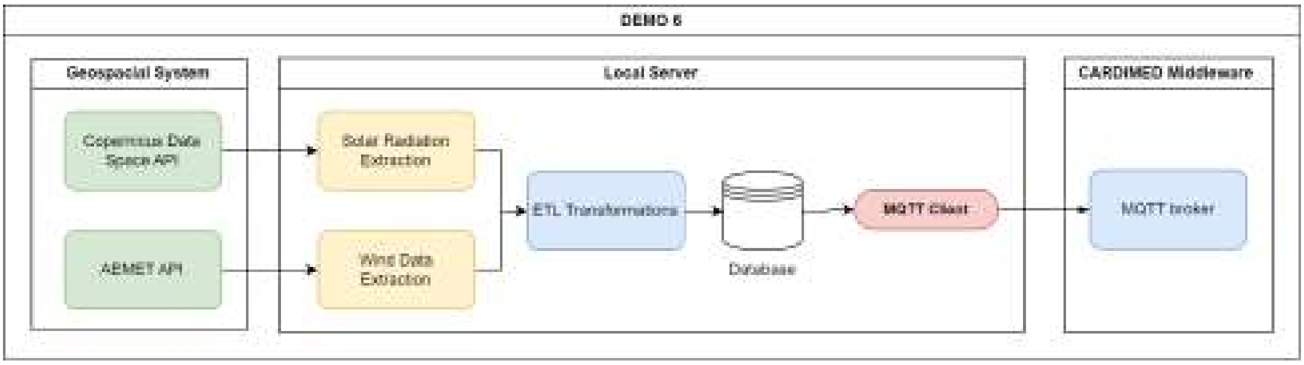


Figure 84: Architectural data integration diagram, where solar radiation and wind data are computed from rasterise data and collected in the Middleware.

6.7 Data Integration Plan for DEMO7

6.7.1 In-situ Data

For DEMO 7, the in-situ data integration plan involves only the Riverside Streams subdemo, using an IoT system with a HOBO Temperature/RH Data Logger. The data is transmitted via Bluetooth to a person's mobile device and can then be uploaded to the CARDIMED Middleware using a File Server GUI, where metadata can be added if needed. This data flow is shown in Figure 85.

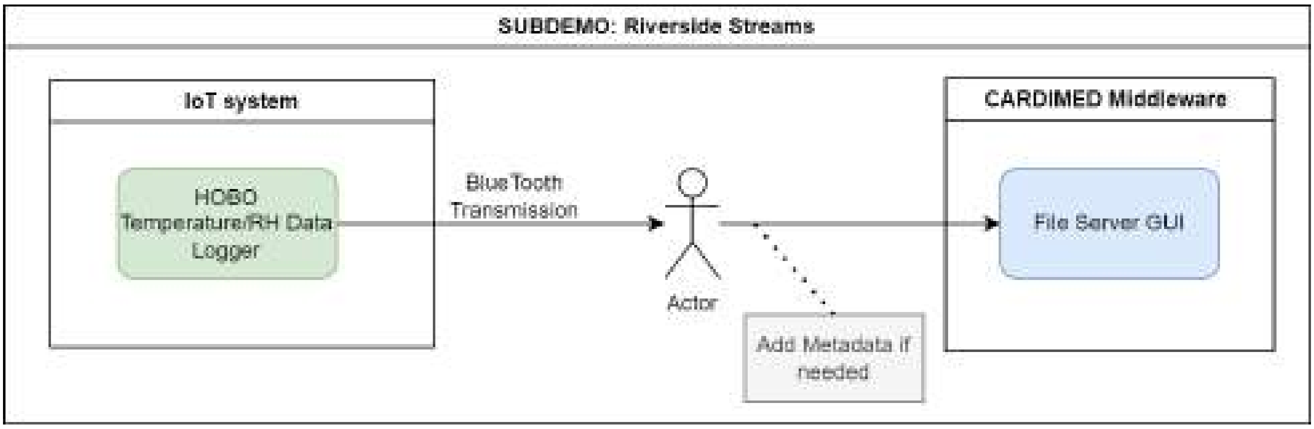


Figure 85: In-situ data integration plan for Riverside Streams

6.7.2 Structured Data from Custom Services

Various datasets that are related to both Riverside Streams and Montados subdemos need to be integrated that are not currently provided by any existing service.

SubDemo 7.1: Riverside Streams

For the Riverside Streams subdemo, such structured data includes the richness and cover of typical plant species, the number of planted trees, the survival rate of planted trees and shrubs per year, the number of berry plants planted, and the cover area of invasive alien species (IAS). Additionally, the number and area of habitats restored through field sampling and GIS analysis of very high-resolution (VHR) aerial images can also be integrated. This data is collected and uploaded manually to the CARDIMED Middleware using a File Server GUI, adding extra metadata if needed as shown in Figure 86.

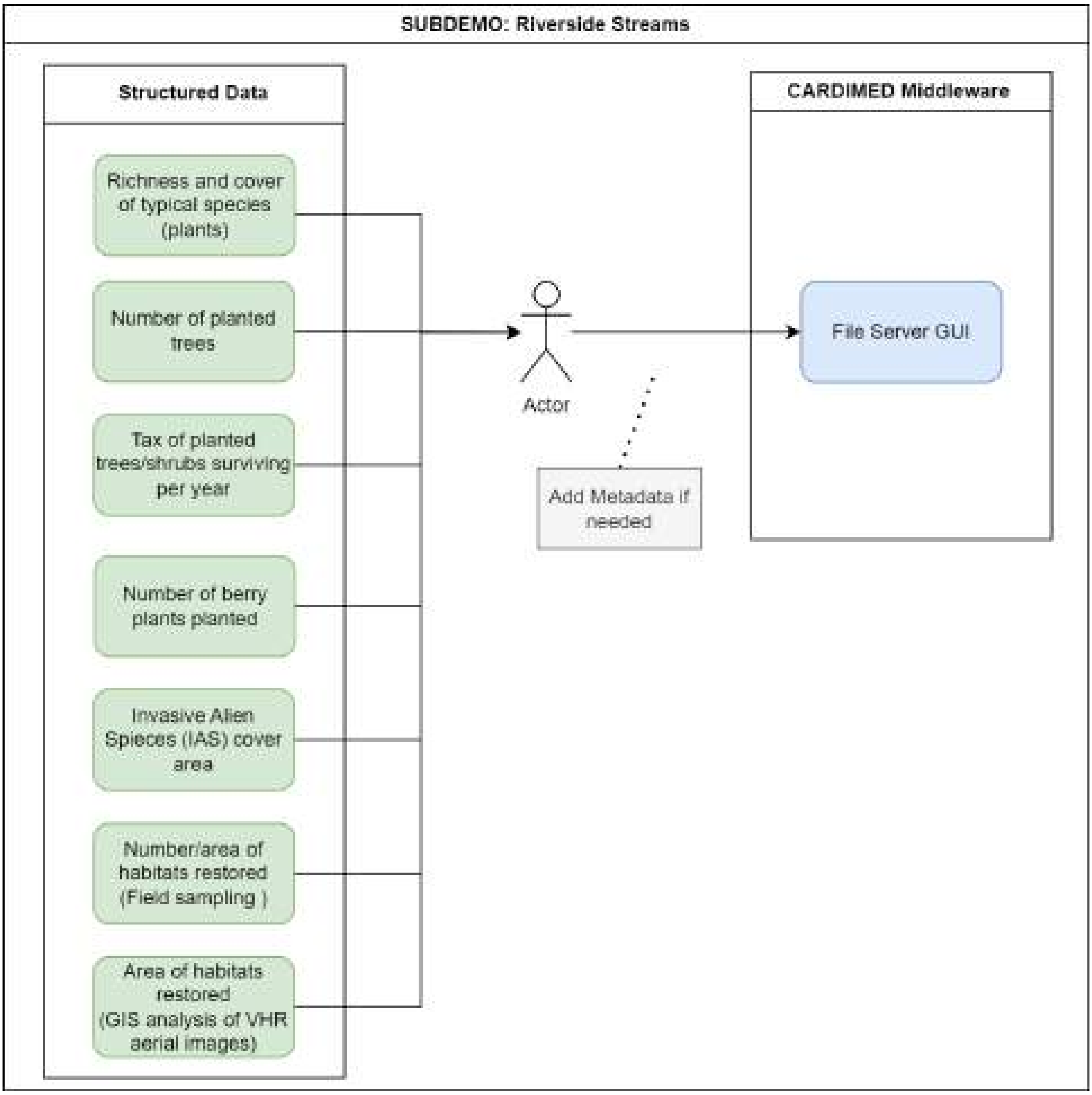


Figure 86: Data integration of structured data that are not provided by existing services for Riverside Streams

SubDemo 7.2: Montados

For the Montados sub-demo, structured data includes the total shrub cover percentage, tree regeneration metrics, the area of the Montado landscape that is improved, and the area of habitats restored. Similar to the Riverside Streams subdemo, this data is uploaded manually to the CARDIMED Middleware via a File Server GUI, as shown in Figure 87.

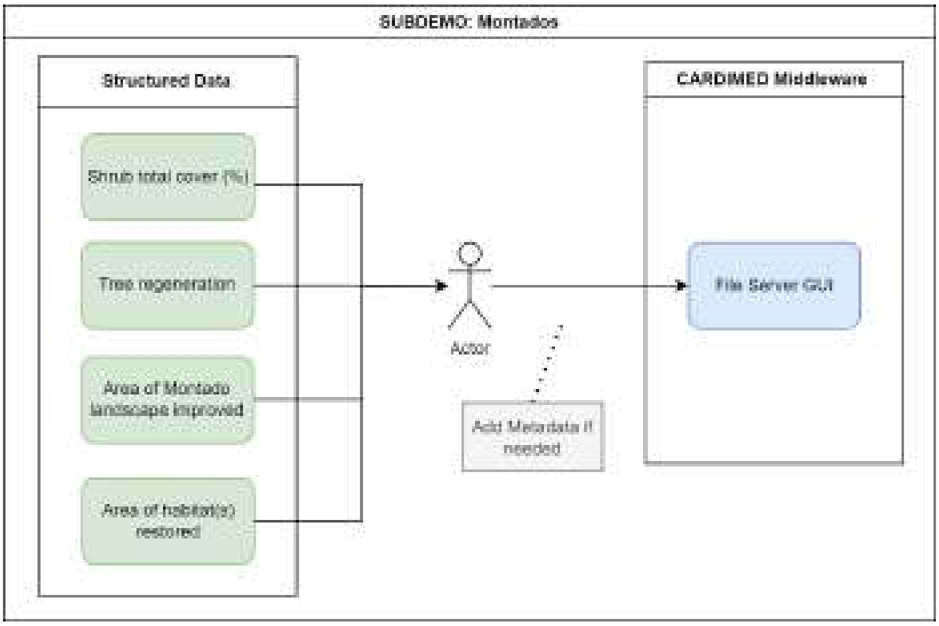


Figure 87: Data integration of structured data that are not provided by existing services for Montados

6.7.3 Data from existing Services and Data Platforms

For both Riverside Streams and Montados subdemos, data from the Climate Adapt platform is manually downloaded and integrated into the CARDIMED Middleware, as shown in Figure 88. This includes structured datasets such as mean temperature, minimum and maximum temperature, growing degree days, climatological heatwave days, high fire danger days, and aridity.

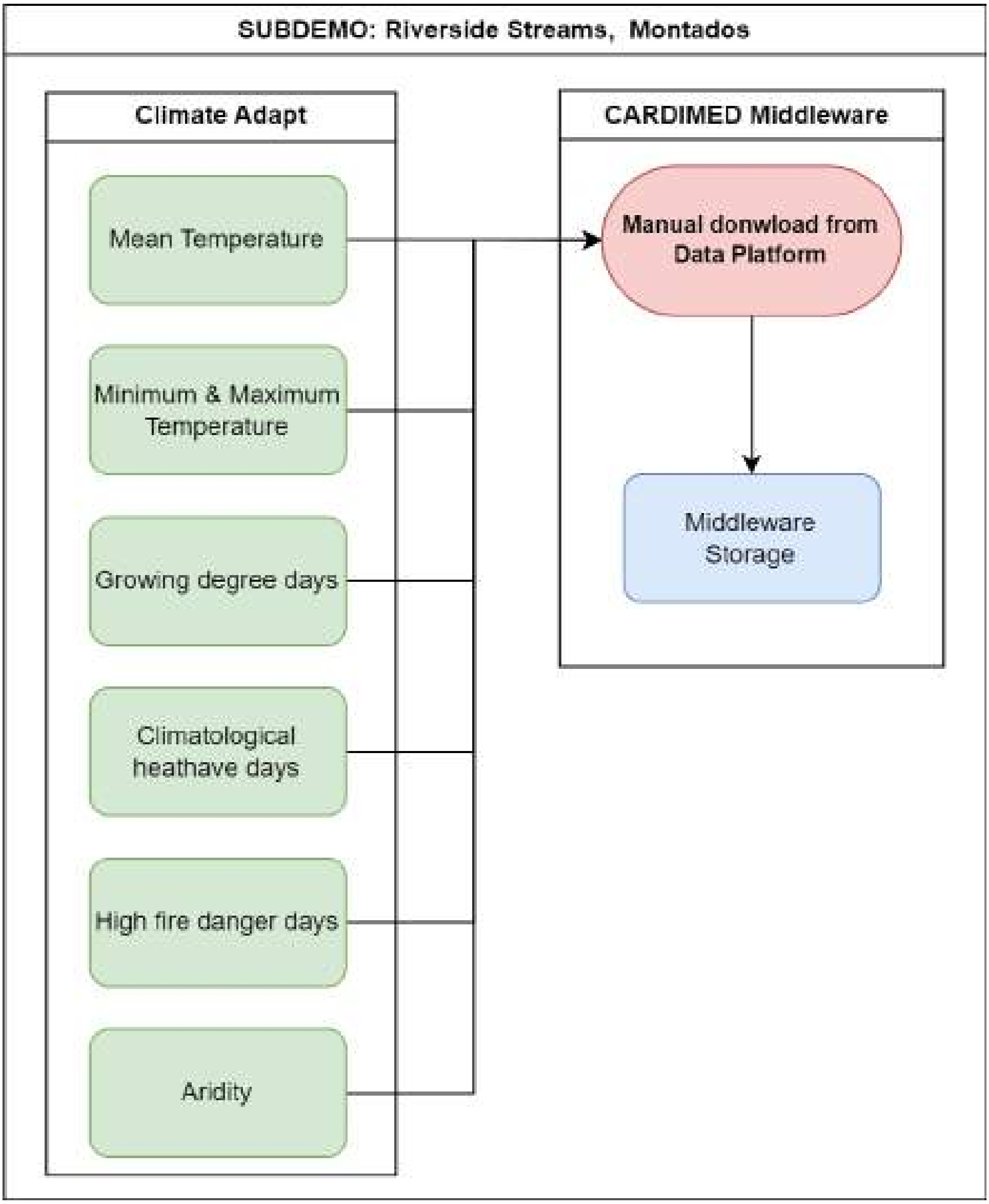


Figure 88: Data integration plan for data from Climate Adapt Platform for Riverside Streams and Montados sub-demos

For the Riverside Streams subdemo, additional structured data can be sourced from ESRI Portugal, mainly the Vegetation Cover in percentage. The data from this platform can be accessed through an ESRI REST endpoint. So, a dedicated REST client needs to be developed to retrieve this data and transfer it to the CARDIMED Middleware, where it is stored for further use, as shown in Figure 89.

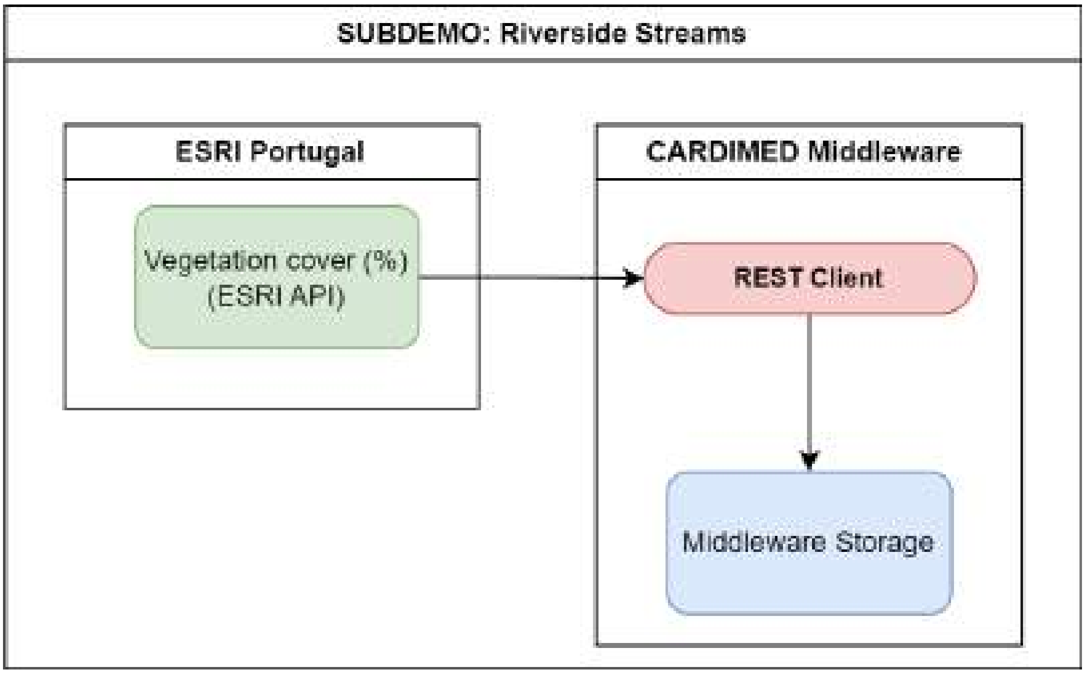


Figure 89: Data integration plan for Vegetation Cover from ESRI Portugal Platform for Riverside Streams

6.7.4 Copernicus Earth Observation Data

For both the Riverside Streams and Montados subdemos, Copernicus Earth Observation data can be sourced from the Copernicus CORINE Land Cover dataset. This data can be ingested and transformed on the ICCS EO Platform, where they can be accessed through the EO Platform STAC API. So, in order for this data to finally reach the CARDIMED Middleware, a STAC REST Client needs to be developed, as shown in Figure 90.

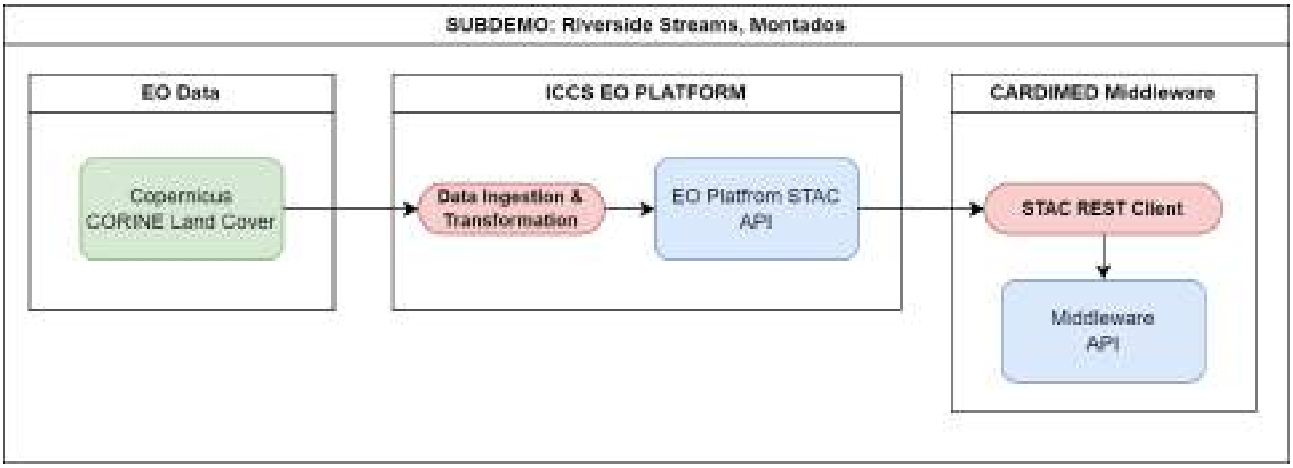


Figure 90: Integration plan for Earth Observation data from Copernicus Land Cover for Riverside Streams and Montados

For the Riverside Streams subdemo, additional EO data can be collected from the Copernicus Total Vegetation (%) dataset. This data can also be ingested and transformed on the ICCS EO Platform and transferred to CARDIMED Middleware with the same procedure, using a STAC REST Client, as shown in Figure 91.

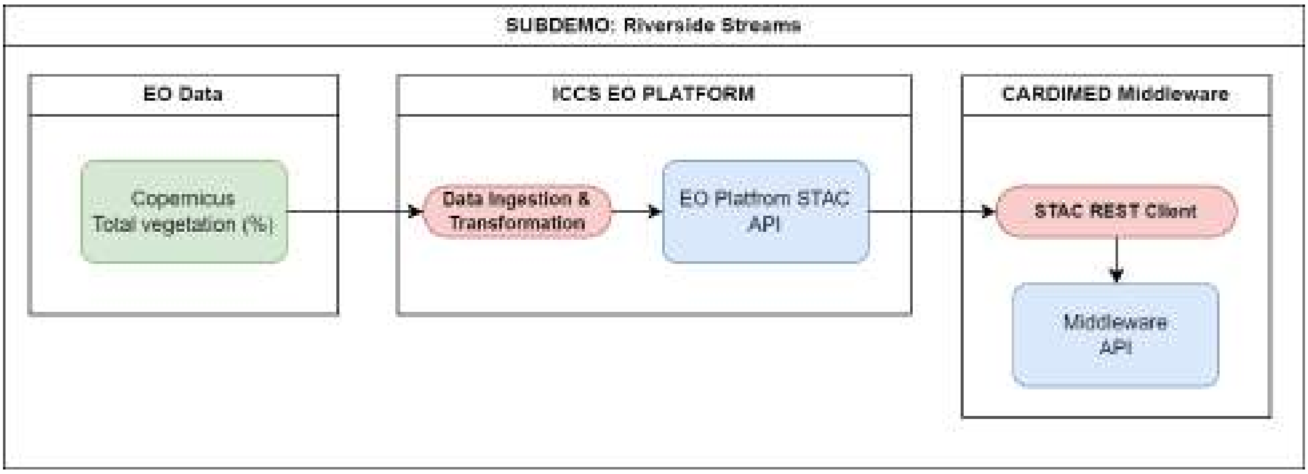


Figure 91: Integration plan for Earth Observation data from Copernicus Total Vegetation for Montados.

6.8 Data Integration Plan for DEMO8

6.8.1 In-situ Data

For DEMO 8, the data integration process involves an IoT system consisting of water sensors and weather stations. The water sensors transmit data via a 3/4G connection to the IZTECH platform, where the data is stored. From this platform, data can be ingested to the CARDIMED Middleware using a dedicated REST or FTP client depending on which can be supported at the final release. Weather station data will be collected by a person, who may add metadata if needed, and then uploaded to the CARDIMED Middleware using a File Server GUI. These approaches are shown in Figure 92.

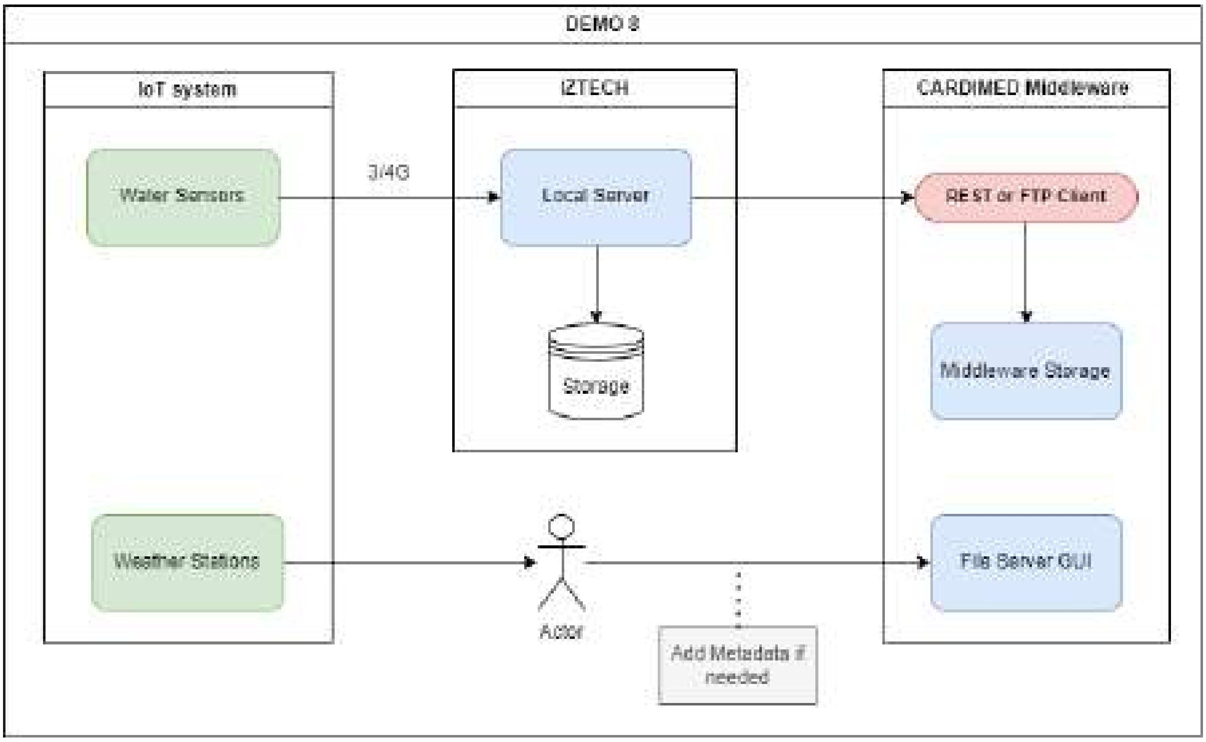


Figure 92: Data integration plan for in-situ sensors of DEMO 8

6.8.2 Laboratory Data

The laboratory data that can be collected in DEMO 8 include measurements of pH, major anions (Cl^-, NO_3^-, NO_2^-, SO_4^{2-}, CO_3^{2-}, HCO_3^-), cations (Ca^{2+}, Mg^{2+}, Na^+, K^+), heavy metals, groundwater temperature, pH, electrical conductivity, and groundwater level. After all this data is measured and collected by the laboratory personnel can be then uploaded manually to CARDIMED Middleware using a File Server GUI, adding any metadata if needed. This process is shown in Figure 93.

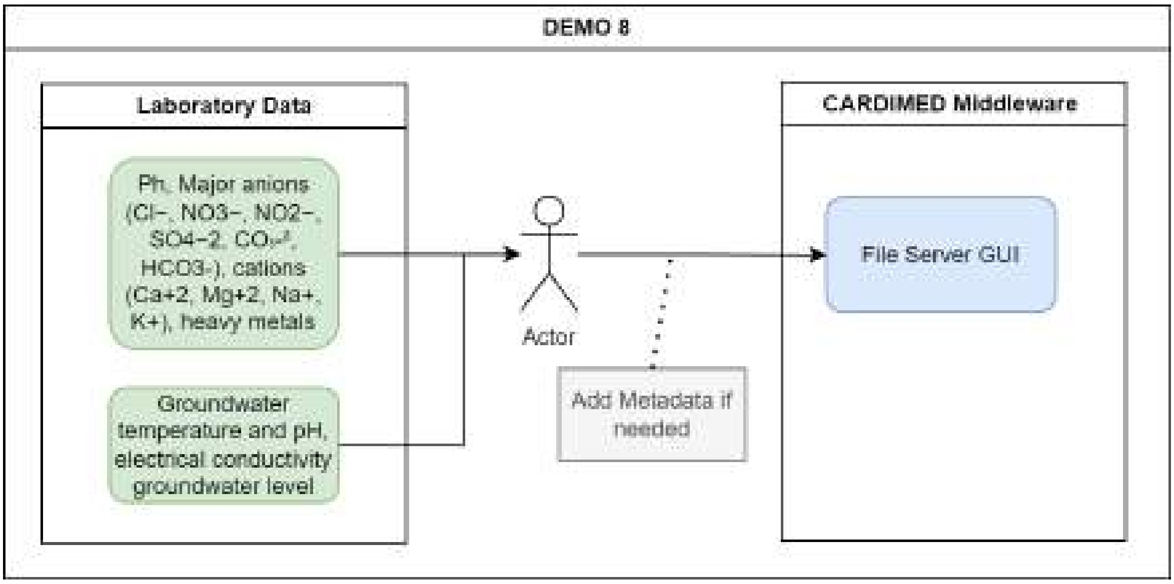


Figure 93: Data integration plan for laboratory data of DEMO 8

6.8.3 Unstructured Data

The unstructured data, related to DEMO 8 includes information on mammalian presence, bird presence, the current numbers of goats, sheep, and cows in the project area, and the severity of poaching in the project area. These datasets are typically stored in PDF format. This data must be accompanied by metadata to maintain consistency and traceability. They can then be uploaded to the CARDIMED Middleware using a File Server GUI as shown in Figure 94.

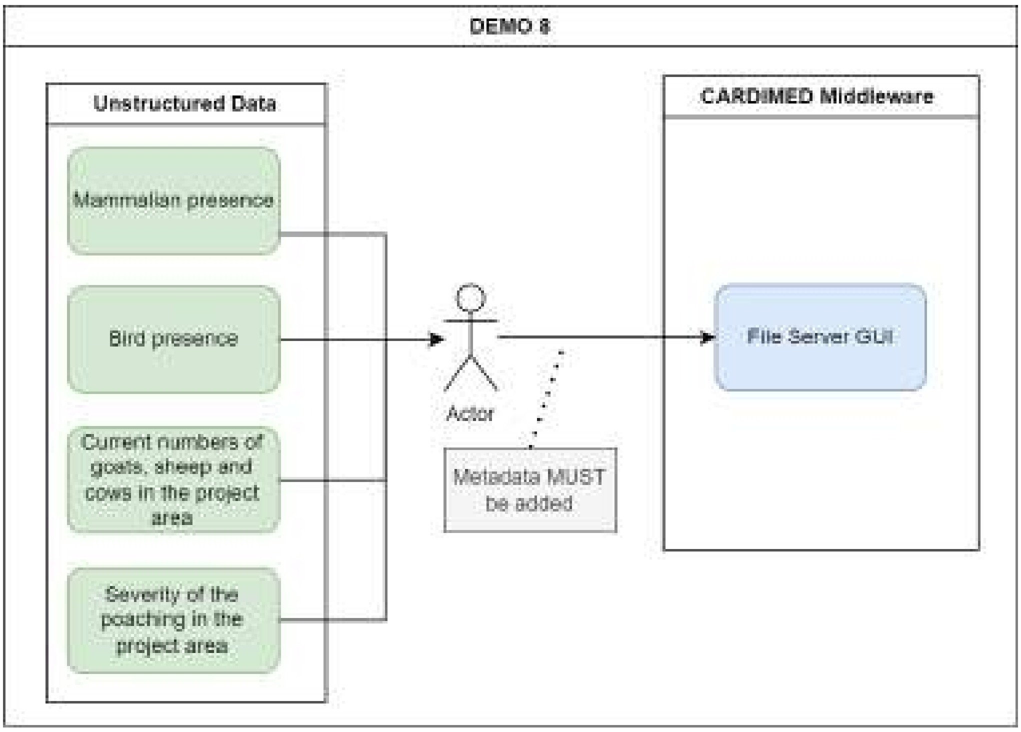


Figure 94: Unstructured data integration plan for DEMO 8

6.8.4 Structured Data from Custom Services

Structured data for DEMO 8 includes metrics such as livestock carrying capacity, biogas plant energy production, photovoltaic energy production, and vegetation change. Additionally, it includes biodiversity monitoring data, such as spring and autumn bird migration monitoring, breeding bird atlas data, regular bird monitoring, and observations of amphibians, reptiles, odonates, and medium and large mammals.

This data is prepared and stored in CSV or XLSX formats. Once prepared, the data can be then uploaded to the CARDIMED Middleware using the File Server GUI, adding any metadata if necessary, as shown in Figure 95.

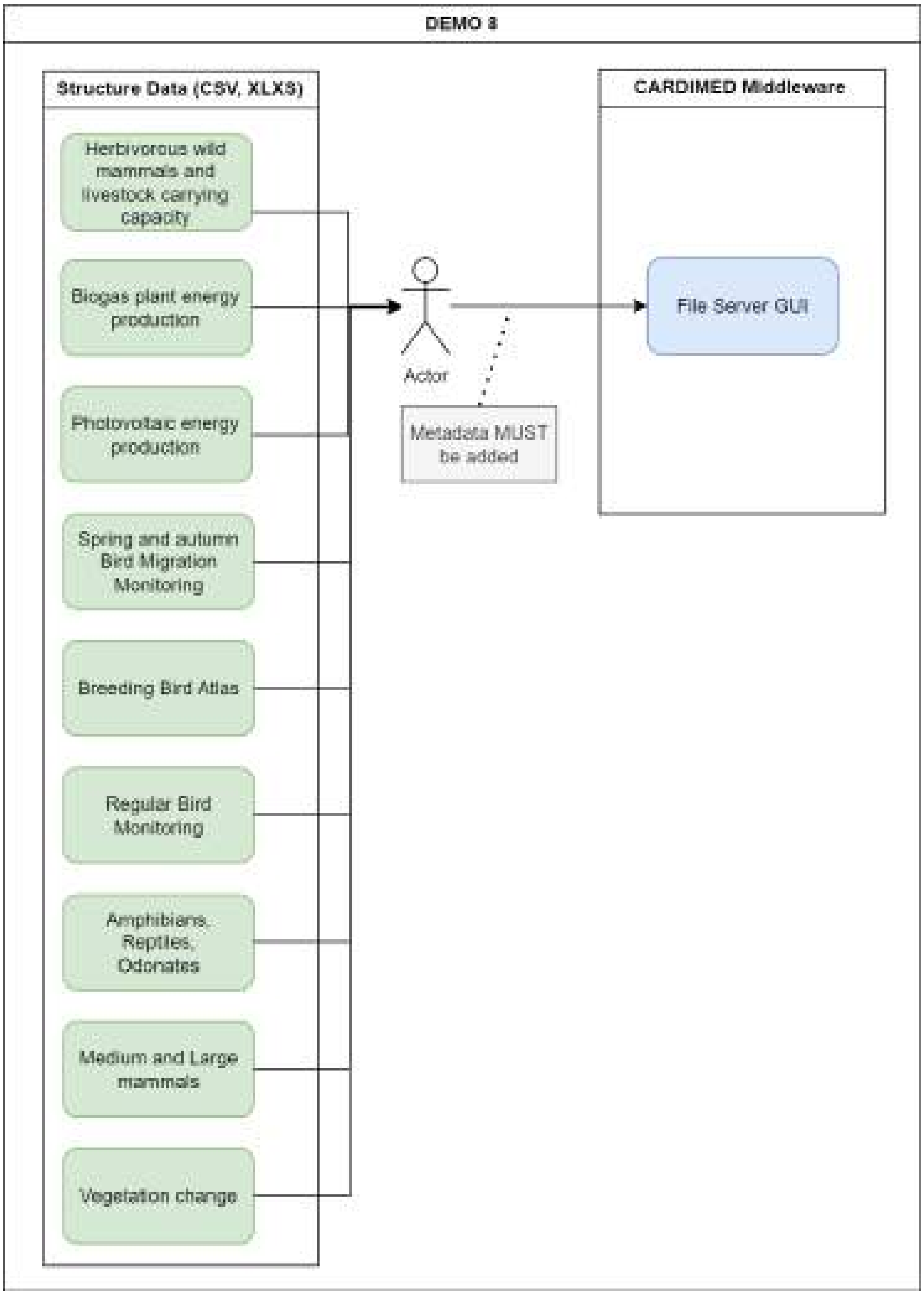


Figure 95: Structured data integration plan for DEMO 8

6.8.5 Data from existing Services and Data Platforms

Data from existing platforms related to DEMO 8 includes precipitation, temperature, and evaporation data sourced from the Ministry of Environment, Urbanization, and Climate Change, as well as bird presence data from eBird.org. Precipitation, temperature, and evaporation data are manually downloaded from the Ministry's data platform once a year and ingested into the CARDIMED Middleware. Bird presence data from eBird.org can be accessed via a REST Client, which retrieves the data and transfers it to the CARDIMED Middleware. Both datasets are stored in the middleware storage and this integration plan is shown in Figure 96.

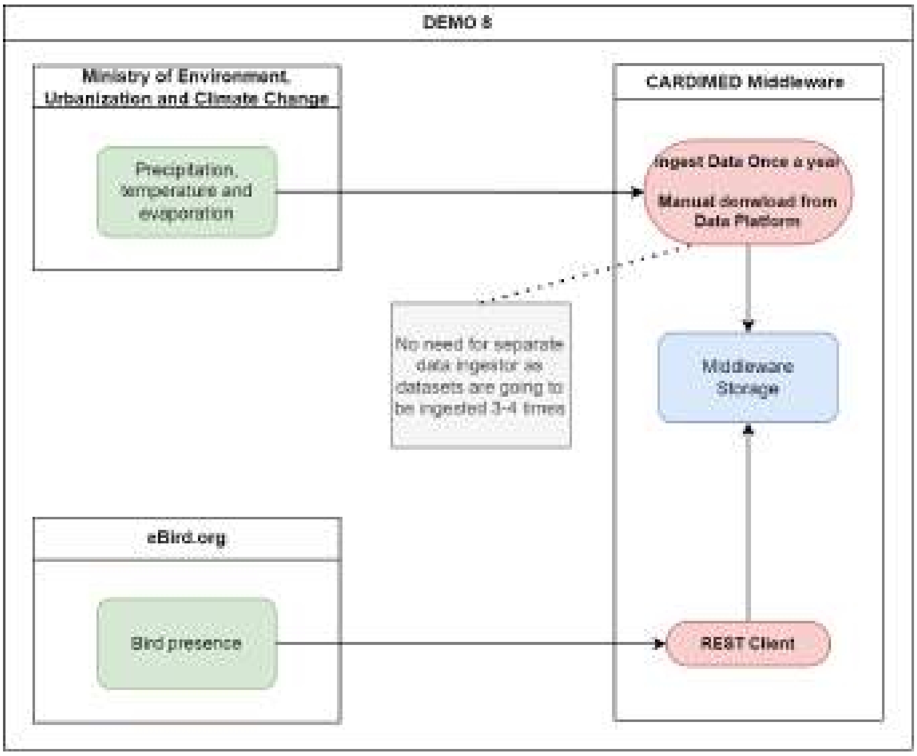


Figure 96: Data integration plan from existing services and data platforms for DEMO 8.

6.8.6 Copernicus Earth Observation Data

Copernicus Earth Observation data for the needs of DEMO 8 can be sourced from the Copernicus CORINE Land Cover dataset. This data can be ingested and transformed onto the ICCS EO Platform, where they can be accessed through the EO Platform STAC API by a STAC REST Client and be available by the Middleware as shown in Figure 97.

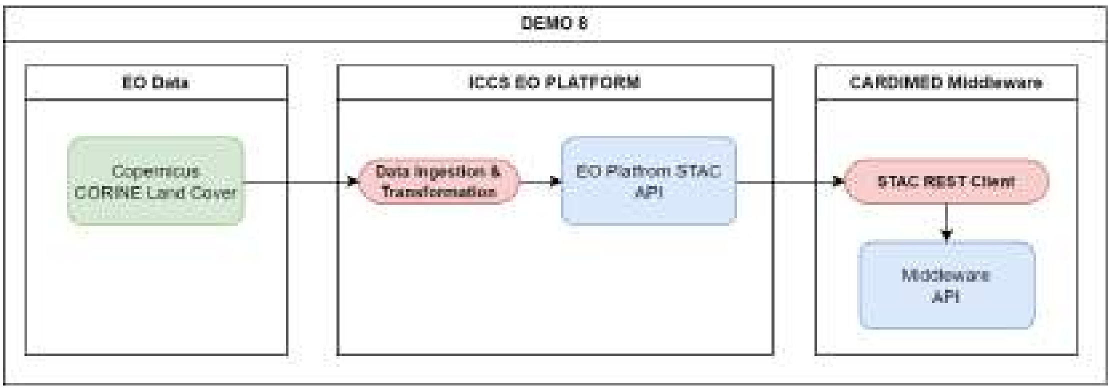


Figure 97: Integration plan for Earth Observation data from Copernicus Land Cover for DEMO 8

6.9 Data Integration Plan for DEMO9

6.9.1 In-situ Data

The in-situ data collection system of DEMO 9 integrates various IoT sensors (Figure 98). The integration plan for these falls into two categories. One category involves the sensors that send data to Smart Sense Platform which includes air quality sensors, weather stations and acoustic sensors. Data produced by these sensors can be retrieved from the SMART-AIRQ API by a dedicated REST client and then stored in Middleware's storage. The other category involves sensors that send data to a local server which includes water quality sensors, weather stations, soil sensors, water level sensors in Tanks and flowmeters. For these sensors, an MQTT client will be developed that collects the data from the local server and sends them to the CARDIMED Middleware via an MQTT Broker.

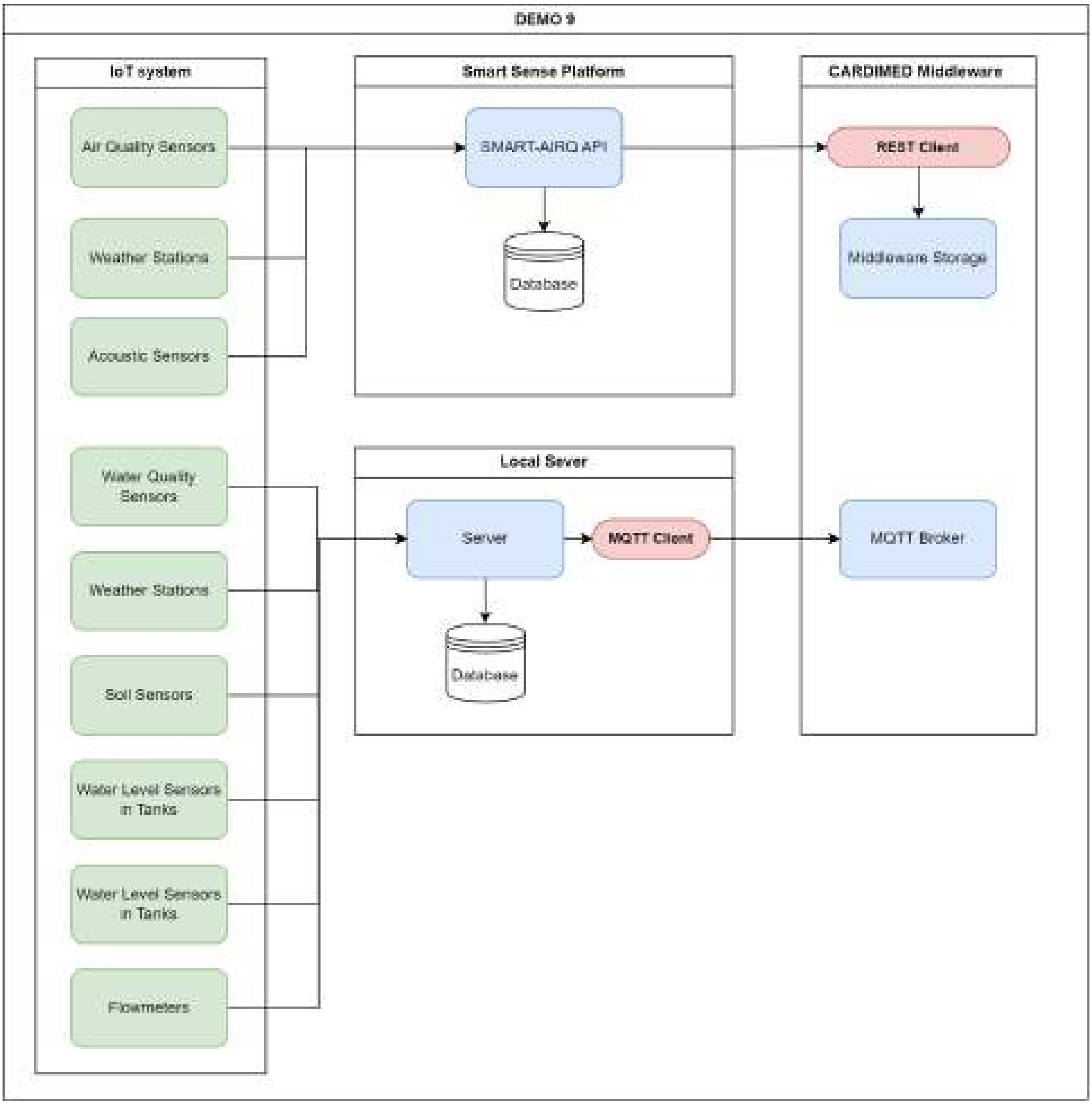


Figure 98: Data integration plan for in-situ sensors of DEMO 9

6.9.2 Laboratory Data

Laboratory data for DEMO 9 includes measurements of biomass, nutrients (nitrate, ammonium, phosphate), and metals and minerals. This data is collected by the laboratory personnel and can be then manually uploaded, accompanied with some metadata if needed, to the CARDIMED Middleware using the File Server GUI as shown in Figure 99.

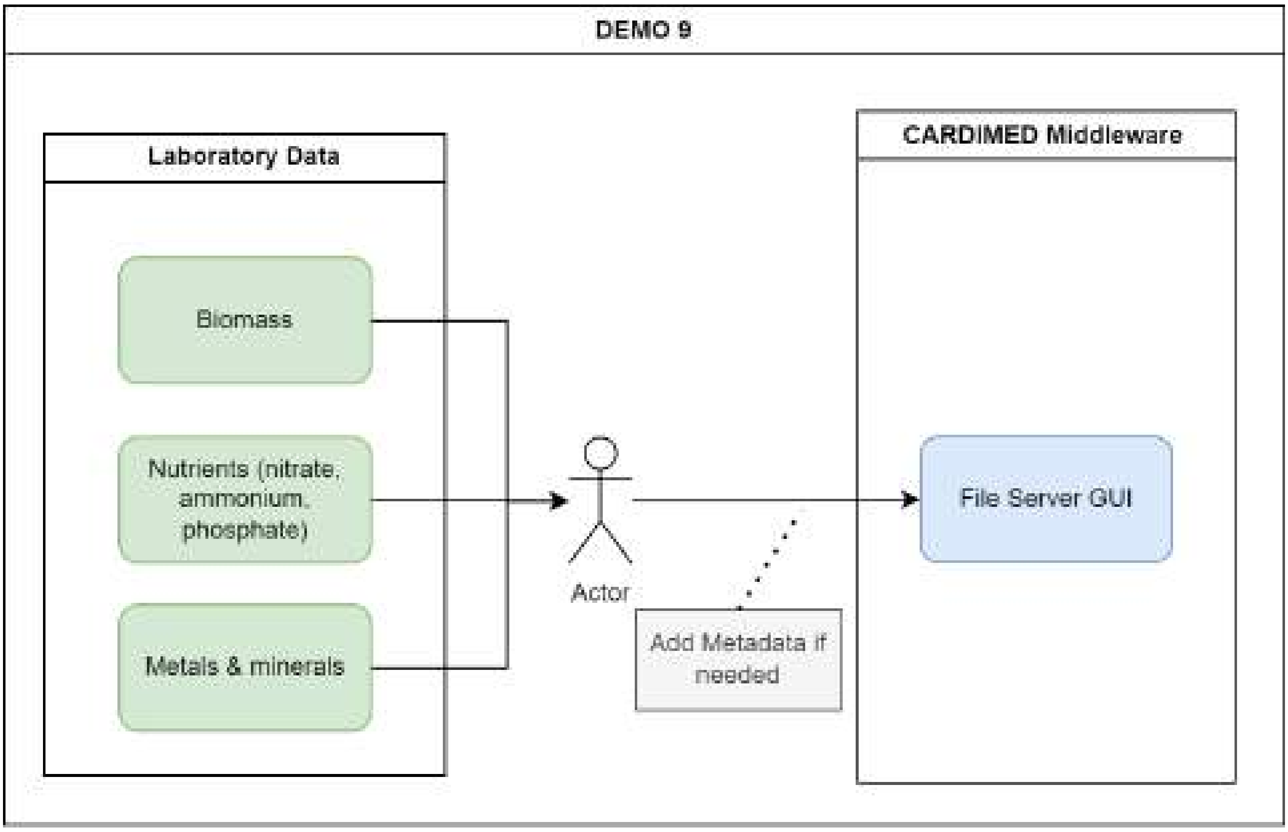


Figure 99: Data integration plan for laboratory data of DEMO 9

7 Conclusion

In this deliverable, we adopted the DLP methodology and thus identified 291 unique data streams, which are planned to be collected from the nine demos of the CARDIMED project. These data streams include both the existing and the upcoming data sources. Prior to the demonstration of the data collection strategy, an extensive desktop research approach managed to identify a plethora of indicators that can be used within this project in order to assess the impact of the deployed NBS. For the analysis of the outcomes gained from the DLP methodology, it appeared that the consortium partners and the local organisations are the data providers. The contribution of the EU organisation is observed to a smaller extent. Furthermore, the most widely used known and standardised storage formats are used, and the majority of the cases will be provided through a manual upload process to the centralised file server of CARDIMED. However, the most lightweight formats (e.g., Apache parquet, FlatGeobut and GeoPackage) have not been widely adopted so far, with only one exception to be reported in DEMO 5 (Figure 31).

Similar viewpoints are observed in the data accessibility interfaces with the file server of the APIs to support the majority of the data integration plans. Occasionally and mainly in IoT systems, the lightweight Pub/Sub mechanisms have been chosen and supported by the LoRaWAN data transmission protocol. Finally, a rather mixed landscape was observed in the legal openness, with demos 6 up to 9 revealing their intention to release openly the generated or existing data products, observing the opposite perspective in the remaining demos. This will guide in the long run the obligations that the consortium in accessing and modifying these data streams. All the aforementioned analyses served a wider objective, as they facilitated the design of bespoken data integration plans for every data source and every data accessibility interface, addressing all the specificities and spatiotemporal characteristics. This analysis should be treated as a guideline for the future development of the MW platform of the CARDIMED project and the upcoming data collection campaigns during the pilot demonstrations. Nevertheless, it should be reported that slight modifications might be required in this initial strategy based on the insights and feedback gained after the first pilot phase. However, the outcomes of this deliverable firmly advocate that both the Data Ecosystem Mapping and the Data Integration Plans are crucial steps in the process of designing a robust NBS framework, as they assure the provision of solid evidence of their beneficial contribution to the prevention of climate crisis, contributing this way on the upcoming climate resilience strategies.

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9 Annex

*Table 13: Presentation of the indicators that are tailored to evaluate the NBS impact assessment for the Biodiversity monitoring. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; R: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative.*

Indicator	Unit	Description	Climate strategy
Pollinator Occupancy Indicator	Number	This index estimates the overall area where each pollinator species is found, providing a measure of their occupancy. It is calculated as the arithmetic mean of the scaled species-specific occupancy estimates.	ER
Pollinator Abundance Index	Number	This index measures the number of pollinators present in a given area, providing a direct measure of their abundance. It can be used to track changes in pollinator populations over time.	ER
Pollinator Community Index	Number	This index assesses the richness of pollinator communities within a specific area. Richer pollinator communities will likely provide higher pollination services.	ER
Pollinator Habitat Index	Number	This index evaluates the quality and quantity of pollinator habitats, such as the presence and diversity of flowers, which are essential for pollinator survival and activity.	ER
Pollinator Service Index	Number	This index measures the overall pollination services provided by pollinators, including the pollination of crops and wildflowers. It can be used to assess the impact of changes in pollinator populations on ecosystem health.	ER
Butterfly specific: Regionally Informed Abundance Index	Number	This index supports integrative analyses across butterfly monitoring schemes by providing a standardized measure of abundance for different butterfly species.	ER
Butterfly and location-specific: Species Collated Indices	Number	These indices were produced for each monitoring scheme, providing a comprehensive overview of the species present in a given area.	ER
Grassland Butterfly Index (GBI)	Number	GBI is based on European species trends and, when applied at the European level, on supranational species trends.	ER
Red List Index (non-insect species)	Number	This version of the RLI is based only on data for birds and mammals that are known or inferred to be pollinators and shows changes in the aggregate extinction risk of pollinator species over time.	ER
Syrphid the Net (StN) for syrphid flies	Number	StN is a large database proposed to evaluate ecosystems on the basis of the presence of syrphid flies in relation to what is to be expected in a given environment (based on CORINE	ER

		and EUNIS systems). Syrphids are potentially very good bioindicators due to their many species and adaptations, relatively easy identification and stable taxonomy.	
Ground Beetle Index (GrB)	Number	Carabids are frequently used to indicate habitat alterations, since the species are expected to react to disturbance according to whether they have generalist or specialist lifestyles. Carabid beetles are well known taxonomically and ecologically and have been used widely in different studies	ER
Pollinator habitats changes	%	Based on surveys	ER
Pollinator species changes	%	Based on surveys	ER
Ecotoxicology factor (EcoF) –	A concentrati on unit	EcoF is based on (i) an evaluation of the concentration of pollutants for which an effect is measured in 50% of a population (EC50) and (ii) the time needed for 50% of a pollutant to disappear (DT 50)	R
Ecological connectivity	unitless	Ecological connectivity refers to the degree to which landscapes facilitate the movement of species, genetic material, and ecological processes between habitats, ensuring biodiversity and ecosystem resilience.	R
Alien species density	individuals/ m^2	Alien species density measures the number of non-native species present per unit area within an ecosystem. This indicator helps assess the potential impact of invasive species on biodiversity, ecosystem functions, and native species populations.	M
QBR Index (River Forest Quality)	Score 0-100	The QBR Index (River Forest Quality) evaluates the ecological quality of riparian forests by assessing factors such as vegetation cover, structure, and connectivity. It is expressed as a score (0–100) and serves as an indicator of the health and functionality of riverine ecosystems.	R
Riparian Quality Index (RQI)	unitless	The Riparian Quality Index (RQI) assesses the ecological health of riparian zones by evaluating vegetation composition, soil stability, and habitat connectivity. It provides a quantitative score to monitor the condition of riparian ecosystems and their ability to support biodiversity and ecosystem services.	R
River continuity	%	River continuity refers to the uninterrupted flow of water, sediments, and organisms along a river system, both longitudinally (upstream to downstream) and laterally (across floodplains). This indicator is crucial for assessing the ecological integrity of rivers and the impacts of barriers like dams or weirs on ecosystem connectivity and species migration.	M

River morphology	unitless	River morphology refers to the physical structure and form of a river system, including its channel shape, flow patterns, sediment transport, and the dynamics of riverbanks and floodplains. It is typically assessed through measurements of channel width, depth, slope, sediment composition, and riverbed characteristics, often expressed in units like meters (m), square meters (m^2), or percentage (%) for changes in structure over time.	M
Abundance and diversity of functional groups	Number (unitless)	The indicator is a quantitative measure reflecting how many different functional groups of plants (e.g. graminoids, forbs, and bryophytes) are present in a community (study area) and is expressed by the Shannon Diversity Index, which quantifies the uncertainty in predicting the functional group identity of an individual randomly selected from the study area.	R
Age of tree plantations	year	Year since tree plantations	R
Animal species potentially at risk	No./ha	Animal species potentially at risk refers to species that are vulnerable to decline or extinction due to factors such as habitat loss, pollution, climate change, or invasive species. This indicator is often quantified by the number of species classified as endangered or threatened according to conservation status assessments, typically expressed in terms of species count or percentage of total species in a given area.	R
Area cleared of alien species of Union Concern	ha	Area cleared of alien species of Union Concern	R
Area cleared of invasive species	ha	Area cleared of invasive species	R
Area cleared of parasitic plant species	ha	Area cleared of parasitic plant species	R
Area covered by alien species of Union Concern	ha	Area covered by alien species of Union Concern	R
Area of parasitized trees	Ha	Area of parasitized trees determined by field work, satellite imagery, aerial imagery or LIDAR data	R
Area of plant habitat-forming or habitat engineers	ha	Area covered with plant habitat-forming or habitat engineers (e.g. holm oak, beech, reed, eelgrass...)	R
Area of tree plantations	ha	Area covered with tree plantations	M

Area or biomass of key plants in plant-animal trophic interactions	ha or t	Area or biomass of key plants in plant-animal trophic interactions in a given area or habitat	R
Article 17 Habitat Richness	No./grid	Habitat richness is a crucial component of biodiversity and habitat density describes how many bird habitats are encountered within a Functional Urban Area. This can be calculated using a count of Article 17 habitat types per hexagonal grid cell, derived from a modified Article 17 dataset, the measure of habitat richness of Article 17 habitats using bird habitat density as a habitat richness proxy as defined in The European Urban Biodiversity Index (EUBI).	R
Biomass	t/ha	Quantities per unit area of living or dead biomass of plants, animals or microbes.	M
Biomass removed of alien species of Union Concern	t/ha	Biomass removed of alien species of Union Concern	R
Bird species richness	No./grid	Bird species richness refers to the total number of different bird species present in a given area or ecosystem. It is commonly measured by simply counting species, with the result expressed as a species count or species per unit area (e.g., species per square kilometre).	R
Bryophyte and lichen species richness and cover in urban environments	Number and %	Cryptogamic species like bryophytes and lichens, are sensitive to environmental conditions and pollution, and used as bio-indicators of air quality changes in urban and non-urban environments	R
Burned area	ha	Area of burned vegetation	M
Change in urban bird species		Change in number of species of birds in urban area/built-up areas in the city	R
Change in the age structure of populations	Number	Change in the age structure of populations, such as age of animals or diameter of trees	R
Changes in phenology	%	Changes in phenology or presence of phenological mismatch among taxa or between taxa and seasonal events	R
City Biodiversity Index	%	Number of native species detected in the urban area, compared to a baseline number of species. Vascular plants, birds, and butterflies have been defined in the City Biodiversity Index as core taxonomic groups to be followed in all cities. On top of these, cities are encouraged to select two supplementary taxonomical groups chosen to best reflect local biodiversity. The supplementary taxonomical	R

		groups can include, e.g., bryophytes, fungi, amphibians, reptiles, fish, beetles, spiders, seagrasses or others.	
Conservation status of area of habitats under the EU Habitats Directive	Good, Poor, Bad, Unknown	Conservation status of area of habitats under the EU Habitats Directive	R
Conservation status of future prospects of habitats under the EU Habitats Directive	Good, Poor, Bad, Unknown	Conservation status of future prospects of habitats under the EU Habitats Directive	R
Conservation status of quality of habitats under the EU Habitats Directive	Good, Poor, Bad, Unknown	Conservation status of quality of habitats under the EU Habitats Directive	R
Conservation status of range of habitats under the EU Habitats Directive	Good, Poor, Bad, Unknown	Conservation status of range of habitats under the EU Habitats Directive	R
CORINE/EUNIS habitat richness	No./grid	Habitat richness is a crucial component of biodiversity and habitat density describes how many habitats are encountered within an area. This can be calculated using a count of CORINE or EUNIS habitat types per grid cell.	R
Deadwood in ecosystems	Volume or Number	Deadwood encompasses all woody material that is no longer living, including stems, branches, twigs, and roots, but excludes deadwood parts of living trees. It is recommended to differentiate between standing and lying deadwood. It should be calculated as the number of logs or their volume in a selected area.	M & R
Density of invasive alien species of Union Concern	individuals/ ha	Density of invasive alien species of Union Concern	R
Density of invasive species	individuals/ ha	Density of invasive species in a given area or ecosystem	R
Description of cover: perennials/annuals v.	%	Proportion of perennials/annuals plants, and proportion of spontaneous/planted plants	R

Spontaneous/planted			
Distribution of blue space	%	Measure change in blue space (ponds, rivers, lakes) in urban area (%, hectares or ha/100km) due to NBS based on more applied and participatory methods	R
Drought tolerant species	Number	Number and abundance of drought tolerant or low water consumption species used in a project	R
Ecological integrity	%	Ecological Integrity is a holistic measure of ecological value and refers to an ecosystem's capacity to support and maintain ecological processes and diverse communities of organisms. It is typically quantified in terms of a measure of 'Intactness (% score or Index). An ecological integrity assessment is a multi-metric index that assigns ranked ecological scores to a variety of spatial and ecological parameters (Brown and Williams 2016). It assesses ecological integrity using data based on remotely sensed landscape characteristics such as patch size and surrounding land use, some abiotic factors such as hydrology, and some attributes of vegetation structure and composition. Multiple remote-sensed datasets are combined to create an index of ecological integrity. Data sources depend upon Methodology. See Faber-Langendoen et al. (2012a; 2012b) for a standard methodology,	R
Edible fruits produced by planted plants	kg	Edible fruits produced by planted plants	R
Evolution of vegetation productivity	N/A	Derived from time series of Sentinel-2AB imagery	M
Family and above richness	Number	The number of different families (or higher taxonomic groups) present in a community, landscape or region	R
Flower surveys	Number and abundance	Larval food plants and adult nectar sources for bee and butterfly species	R
Functional diversity	Number	The diversity of functional traits within a population, community, landscape or region; includes measures of functional redundancy.	R
Functional identity	Number	Metrics indicating dominant functional features within communities or species groups, e.g., mean trait values, and relative abundance of competitive, stress-tolerant and ruderal strategists	R
Future changes in bioclimatic niche dynamics	%	Future changes in bioclimatic niche dynamics of focal habitat/species due to projected different RCP scenarios	R

Generic richness	Number	The number of genera present in a community, landscape or region	R
Genetic diversity	Number	Measures of the number or diversity of genetic polymorphisms or genotypes	R
Grassland area	ha	Area covered with grasslands	R
Green Area Indicators (GAI)	%	The ratio of the area of biologically available surfaces or ecologically effective area (i.e., those covered by vegetation, open water, permeable paving and storm water infiltration, etc.) compared to total parcel area	R
Green Normalized Difference Vegetation Index (GNDVI)	-1 to +1	More sensitive than NDVI to different concentration rates of chlorophyll, which is highly correlated at nitrogen It is calculated as: GNDVI (Landsat 8) = (B05 – B03) / (B05 + B03) GNDVI (Sentinel 2) = (B08 – B03) / (B08 + B03)	M
Growth rate	%	Growth rate of individuals, e.g., change in tree height over time	M
Indicative species (environmental contamination)	Number	Number of indicative plant species that indicate contamination	R
Individuals of alien species of Union Concern removed	Number	Individuals of alien species of Union Concern removed	R
Individuals of invasive species removed.	Number	Individuals of invasive species removed	R
Individuals of parasitic plant species removed.	Number	Individuals of parasitic plant species removed	R
Insectivore increase	and/area	Insectivore increase refers to the rise in populations or diversity of insect-eating species within an ecosystem, which can be an indicator of improved habitat quality or the availability of food resources. This indicator is typically measured by changes in population density or species richness, often expressed in terms of individuals per unit area or species per unit area.	R
Invasive species biomass removed	t/ha	Biomass of invasive species removed	R
Leaf area index (LAI)	dimensionless	amount of leaf area (m^2) in a canopy per unit ground area (m^2)	M

Livestock carrying capacity	AUM = animal unit months	Carrying capacity is the amount of forage available for grazing animals expressed as the number of animal units that can be grazed for a specific time period (currently one month)	M & R
Nectariferous plant species richness and abundance	Number	Species richness and abundance of nectareous plant species that attract insects (bees, butterflies, hoverflies, etc.)	R
Normalized Difference Moisture Index (NDMI)	-1 to +1	Determines the vegetation and soil water content. It is calculated: NDMI (Landsat 8) = (B5 – B6) / (B5 + B6) NDMI (Sentinel 2) = (B8 – B11) / (B8 + B11)	M
Normalized Difference Vegetation Index (NDVI)	-1 to +1	Index to determine vegetation chlorophyll concentrations as a measure of productivity and a plant's ability to photosynthesize Quotient that represents the functional characteristics of the active plant that contrasts the reflectance of the near-infrared and red bands; NDVI values vary between +1 and −1 with higher values for dense vegetation and very low (or negative) values for snow, water and clouds. It is calculated by: NDVI (Landsat 8) = (B5 – B4) / (B5 + B4) NDVI (Sentinel 2) = (B8 – B4) / (B8 + B4)	M
Number and abundance of nitrogen-fixing plants	Number	Number and abundance of nitrogen-fixing plants	M & R
Number and abundance of potential allergenic plants	Number	Number and abundance of potential allergenic plants in a given area	R
Number of conservation priority species	Number	Conservation priority species are those species that are seen as keystone species, umbrella species, or species at particular risk locally, regionally or globally. Evaluation of the number/proportion of conservation priority species in a survey area can represent an effective proxy for overall habitat quality. Conservation priority species can include Article 17 species, European Red Data Book Species, national Red Data Book Species, National Biodiversity Action Plan Species, and local Red Data Book Species. Measure net change in individual conservation priority species numbers or proportion of overall sample in an area affected by NBS.	R
Number of endangered habitats according to the IUCN Red List of	Number	Presence and abundance of endangered habitats according to the IUCN Red List of Ecosystems criteria	R

Ecosystems criteria			
Number of endangered habitats included in the European Red List of Habitats	Number	Presence and abundance of endangered habitats included in the European Red List of Habitats. It uses a modified version of the IUCN Red List of Ecosystems categories and criteria It covers the EU28, Iceland, Norway, Switzerland and the Balkan countries and their neighbouring seas. The Red List covers a much wider set of habitats than those legally protected under the Habitats.	R
Number of endangered species	Number	Number of plants endangered according to the IUCN categories	R
Number of endemic species	Number	Number of plants endemic to a country (restricted to a country)	R
Number of epiphyte species	Number	Epiphytic species are sensitive to environmental conditions like changes in precipitation and temperature, forest management, etc.	R
Number of indicator epiphyte species	Number	Epiphytic species are sensitive to environmental conditions (e.g. changes in precipitation and temperature, forest management, etc.), and some species are also indicators of air quality and provide a warn of the negative effects of pollution	R
Number of invasive alien species	Number	Number of invasive alien species within an area. "Invasive Alien Species (IAS) are animals and plants that are introduced accidentally or deliberately into a natural environment where they are not normally found, with serious negative consequences for their new environment. They represent a major threat to native plants and animals […]"http://ec.europa.eu/environment/nature/invasivealien /index_en.htm)	R
Number of invasive alien species of Union Concern	Years	Number of invasive alien species of Union Concern	R
Number of narrow endemic species	Number	Number of plants that have a very restricted area of distribution, with at least 90% of their occurrences at, or below, the provincial level	R
Urban native birds	No./ha	Number of native bird species within a defined urban area	R
Number of native species	Number	The total number of native species within a defined area (site/neighbourhood/region/city). This can compromise one or more of the following taxonomic groups (it should be	R

		specified which groups are covered): Plants, Birds, Butterflies, Invertebrates, Mammals. Provides an overview of the species diversity, with distinctions able to be made across taxonomic groups if multiple groups can be covered. Defined species can also serve as an indirect "indicator" for habitat quality.	
Number of non-native species introduced	Number	Proportion of non-native animal and/or plant species introduced within an area as part of a nature-based solution scheme. Non-native species are those that have been transported to regions beyond their natural range. In terms of biodiversity objectives, these species can: create a risk of harm if they become invasive; provide biodiversity benefits (e.g., complementing native species provision to extend flowering seasons for nectar and pollen collecting insects); reduce the number of native species within a scheme	R
Number of phytoplankton species sensitive to pollution	Number	Number of phytoplankton species sensitive to pollution	R
Number of phytoplankton species tolerant to pollution	Number	Number of phytoplankton species tolerant to pollution	R
Number of planted individuals died per year	Number	Number of planted individuals died per year	R
Number of potential toxic plants	Number	Number and abundance of toxic plants in a given area (toxic to humans, cattle, etc.)	R
Number of protected species	Number	Number of plants protected at local, regional or supra-regional level	R
Number of ruderal/overgrazing/anthropogenic species	Number	Number of plant species present in a given area or site that are indicative or adapted to disturbed environments (ruderal/overgrazing/anthropogenic...)	R
Number of species detected by citizen science	Number	Cumulative number of species detected by citizen science in public databases (e.g. Inaturalist, planet, etc.) in the area of interest	R

Number of veteran trees per unit area	No./ha	In addition to the multifunctional benefits that are provided by trees, veteran trees play a crucial role in the conservation of biodiversity. An effective measure of conservation of veteran trees is the number of such trees within a unit area (e.g., Formal Urban Area). Although not as old as ancient trees provide holes, cavities and crevices which are especially important for wildlife. In particular, trees with decay-containing cavities are important habitats for many saproxylic invertebrate species. As such, targets and measures of the number of veteran trees in a landscape can contribute the biodiversity conservation objectives and strategies. Whilst the provision of nature-based solutions rarely created new veteran trees (due to long-time sales involved in veteran tree development), nature-based solutions can protect veteran trees, deliver veteranisation of young trees, or cause the loss of veteran trees. As such, this represents a valuable biodiversity indicator,	R
Overall conservation status of habitats under the EU Habitats Directive	Good, Poor, Bad, Unknown	Overall conservation status of habitat types listed in Annex I of the Habitats Directive	R
Parasitic plant biomass removed	t/ha	Biomass of parasitic plant species removed	R
Pastured area	ha	Area of land in use for livestock grazing	R
Percentage of protected natural areas restored and naturalized areas on public land in the municipality	%	Percentage of protected natural areas restored and naturalized areas on public land in the municipality	R
Percentage of tree canopy cover within the city	%	Percentage of tree canopy cover within the city	M & R
Phylogenetic diversity	Number	Measures of branch lengths on a phylogenetic tree for a given group of species	R
Phytoplankton diversity	Number	Number of phytoplankton species in a given water ecosystem	R
Plant mortality	Individuals/ m^2	number of dead plants per square meter	R

Plant mortality	Number	counting the number of dead plants	R
Pollinator habitats changes	Number	Based on surveys	R
Pollinator species changes	Number	Based on surveys	R
The potential of areas likely to host biodiversity	1-5	This indicator enables us to highlight the natural areas susceptible to accommodating a higher level of biodiversity due to their size and shape. Moreover, the use of a Digital-Height-Model (DHM) can make it possible to highlight the mineralized areas (such as city squares for example). Compactness-Surface = ((4*Area*pi) / (Periemter^2)) * Area. Compactness-surface of green spaces from 1 (very low) to 5 (very high)	R
Natural areas in the urban zone	%	Proportion and size of natural areas within a defined urban zone	R
The proportion of areas with endangered habitats included in the European Red List of Habitats	%	Proportion of areas with endangered habitats included in the European Red List of Habitats. It uses a modified version of the IUCN Red List of Ecosystems categories and criteria It covers the EU28, Iceland, Norway, Switzerland and the Balkan countries and their neighbouring seas. The Red List covers a much wider set of habitats than those legally protected under the Habitats.	R
Proportion of endangered habitats according to the IUCN Red List of Ecosystems criteria	%	Proportion of area with endangered habitats according to the IUCN Red List of Ecosystems criteria	R
Proportion of natural/seminatural vs anthropogenic habitats	%	The proportion of natural or seminatural habitats with respect to anthropogenic habitats	R
The proportion of planted individuals who died per year	%	The proportion of planted individuals who died per year	R
Proportion of the life cycle stages of the parasitic plant	% juvenile, vegetative, reproductive	Proportion of the life cycle stages of the parasitic plant (juvenile, vegetative, reproductive)	R
Recovery rate	%	Measures of the recovery rate (sometimes referred to as 'resilience') after disturbances such as extreme climatic events. This is restricted to empirical measures of	R

		resilience, rather than the use of proxies such as functional redundancy.	
Reproductive rate	Number	The reproductive rate of species e.g., fledglings per adult male, young-of-the-year fish numbers, or related measures e.g. runner length	R
Resistance	Number	Measures of ecosystem or species' ability to withstand disturbances such as extreme climatic events. This is restricted to empirical measures of resistance, rather than the use of proxies such as functional redundancy.	R
RNPS -Ratio of Native Plant Species	%	The ratio between the number of native plant species and the total plant species richness (total number of species). Native species are naturally present in the considered biogeographical area.	R
Shannon Diversity Index	Number	The measure of species diversity related to species richness	R
Shannon Diversity Index of Habitats	Number	Indicates the proportion of bare, turf grass, rough grassland and herbs, shrubs, trees and of the built environment	R
Shannon diversity of epiphyte species (including vascular plants, bryophytes and lichens)	Number	Number of different epiphyte species observed and their relative abundances	R
Shannon Evenness Index	Number	The measure of species diversity related to species equality	R
Shrub density	individuals/ ha	number of shrubs per hectare	R
Shrub mortality	individuals/ m2	number of dead shrubs per hectare	R
Soil-Adjusted Vegetation Index (SAVI)	-1 to +1	SAVI is used to correct NDVI for the influence of soil brightness in areas where vegetative cover is low, as the presence of bare soil is found in fluctuating tidal environments case of coastal areas. It is calculated: SAVI (Landsat 8) = ((B5 – B4) / (B5+ B4 + 0,5)) * (1,5) SAVI (Sentinel 2) = (B08 – B04) / (B08 + B04 + 0,428) * (1,428)	R
Species diversity within defined area per Shannon Diversity Index	Number	The Shannon Diversity is a very common index used in ecology to quantify diversity in a community. The index provides more information about the fauna and flora composition than simply area richness. It takes into	R

		consideration both the number of different species observed and their relative abundances.	
Species richness and composition with respect to Indigenous vegetation and local/national biodiversity targets	Number	Species richness and composition with respect to Indigenous vegetation and local/national biodiversity targets	R
Species richness with respect to urbanization gradient	%	Species richness with respect to urbanization gradient in a given area	R
Species under nature conservation designation	Number	No description in the document Connecting Nature	R
Stem density	Number	The absolute or proportional number of stems or individual plants.	M
Targeted habitats	Number	No description in the document Connecting Nature	R
Tree height	m	Calculated with field work or LIDAR	R
Tree mortality	individuals/ ha	number of death trees per hectare	R
Tree stem diameter at breast height	cm	Tree stem diameter at breast height as a proxy of tree age	M
Vegetation height	m	Calculated with field work or LIDAR	M
Years without reoccurrence of invasive species following eradication efforts	Years	Years without re-emergence of invasive species after the application of eradication measures	R
Zooplankton diversity			R
Green urban areas restored to provide fauna habitats	m^2	The surface of green urban areas where actions to improve biodiversity/ecological functionality were undertaken. (Indicator to be adapted for its application to DEMOs in natural areas)	A & R

Urban areas are naturalized providing fauna habitats	m^2	Intervened surface thanks to which a space classified as urban land transforms into a green area with a concrete ecological functionality.	A & R
Green roofs and/or walls provide fauna habitats	m^2	Surface occupied by green roofs and/or green walls in buildings providing habitats for fauna.	A & R
Indicator fauna species presence	%	Indirect measure of the diversity of fauna species in space intervened with actions of restoration, through the selection of indicator species. Identification of the presence/ absence of selected indicator species in the defined sampling points within an intervention area.	A
Indicator fauna species richness	Number	The number of selected indicator species inventoried in an intervention area.	A
Species diversity within a target fauna group or taxa	Number	Shannon Diversity Index of fauna species within a group or taxa (it can be simplified by measuring the Shannon diversity index of fauna groups (e.g. Birds, mammals, reptiles, etc.))	A
Presence of fauna species of interest (endangered, protected or endemic)	%	Proportion of endangered/protected or endemic species (To be considered if it's possible to apply a method allowing to obtain abundance)	A
Presence of invasive fauna species	%	Proportion of invasive fauna species within an area	A
Functionality of green urban spaces for birdlife	Number	It evaluates the quality of urban green spaces to host the maximum diversity of birdlife and allows the monitoring after re-naturalization actions based on the improvement of vegetal cover. The desirable value for this indicator is > 7.5. (According to a standardized method to be described)	A & R
Habitat surface for target fauna group or taxa	m^2	It allows monitoring the habitat area relative to a fauna group of specific species or taxon that is taken as an indicator of the ecological quality for a set of species. (According to a standardized method)	A & R
Presence of species vulnerable to climate change	%	The proportion of fauna species sensitive to climate change	A
Naturalized water surfaces	m^2	Measures the surface of naturalized ponds or other aquatic ecosystems created or restored as a measure of adaptation to climate change that can provide habitat for fauna species	A & R

Fauna shelters installed	Number	Measures the number and effectiveness of wildlife refuges installed as support to biodiversity in climate change scenarios.	A & R

*Table 14: Presentation of the indicators that are tailored to evaluate the NBS impact assessment for the monitoring of soil health and food productivity. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; R: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative.*

Indicator	Unit	Description	Climate strategy
Abundance and activity of microbial functional genes involved in N cycling	Copies number/ g soil	Abundance of genes that indicate the presence of microbes participating in the N cycle	A & R
Aggregation	mm (mean weighted diameter)	Informs on soil structure, that is the arrangement of soil particles into aggregates.	R
C:N ratio	Unitless	C:N ratio as a measure of SOM decomposition in soil	A
Cation Exchange Capacity	meq/100 g	Informs on nutrient storage in soils, nutrient availability to plants, and chemical fertility	A & R
Concentration of heavy metals	ppm	Potential environmental available content of heavy metals in soils based on ISO 17586:2016 using dilute nitric acid.	M
Earthworm counts	Number of individuals per m^3	Indicates soil fertility	R
Electrical Conductivity	dS m^{-1}	Informs about salinization	M
Enchytraeid abundance	number of individuals/cm^3	The abundance of enchytraeid communities, instead of earthworms in cold and wet organic-rich environments, such as moorlands).	A
Enchytraeid reproduction	% mortality	The reproduction test informs on soil pollution	A
Extractable K	mg.kg^{-1}	Influences soil fertility and plant production	A
Extractable P	mg.kg^{-1}	Influences soil fertility and plant production	A
Fungi to Bacteria ratio by PLFA analysis	% of total PLFA	Informs about changes in the dominant soil trophic channels	R
Fungi to Bacteria ratio by quantitative PCR (qPCR)	%	Informs about fungal DNA relative to bacterial DNA in soil	R

Hydraulic Conductivity	mm/h	It is a measure of how easily water can pass through soil	R
Microbial activity: enzyme activity	µmol/g	Extracellular enzyme activity involved in C, N and P cycling	A & R
Microbial Biomass by PLFA analysis	nMol PLFA g^{-1}	Quantitative Microbial biomass estimate that also provides information on global microbial biomarkers	R
Microbial Carbon Use Efficiency CUE	%	microbial partitioning of soil carbon (C) between microbial growth and respiration	M
Microbial functional gene diversity by metagenomics	unitless	Provide information about functional genes in soils (a taxonomic classification may be inferred)	R
N Mineralization	kg N ha^{-1}	Informs about soil Organic matter dynamics and fertility	A & R
Nematode (functional) diversity based on feeding habits	% of upper trophic groups	Informs about resource availability in the soil food web	R
Nematodes Plant Parasite Index (PPI)	Scored between 2 and 5	A maturity index takes into account plant-feeding nematodes.	R
Nematodes Enrichment Index (EI)	Scored between 0 et 100	EI increases with the availability of resources.	A & R
Organic pollutants	concentration of pesticides, AH, etc.)	Determination of organic contaminants in soil	M
Permeation test	cm h^{-1}	Measures the ability of soil to absorb and transmit rainwater.	A & R
pH	pH scale range	The key descriptor of soil chemistry. Also informs about acidification	A
Physical C protected in aggregates	g C kg of soil $^{-1}$	Informs about residence time of organic C in soil	M
Protozoa trophic structure	% of each functional type relative to the total number	Informs on the level of resources in agricultural environments	R
Recalcitrant SOC / Total SOC	%	Informs about C sequestration in soil	M
Relative Normalized Density	%	dry bulk density divided by a critical bulk density, the latter being a function of the clay content	A

Soil Biological Quality Index (QBS)	Natural numbers	Based on soil microarthropods, QBS informs of the "naturality" and maturity of soil communities.	R
Soil Crusting	Soil Crusting Index unitless, Pa crust strength, mm crust thickness	Soil getting a poor aggregation capacity/stability. A crust at the soil surface is created, limiting water infiltration and favouring water runoff	A
Soil macroporosity (SMP)	%	SMP represents the capacity of the soil to provide air for root respiration	A & R
Soil megafauna	Qualitative: traces of activity (burrows, modification of soil and litter, etc.)	Informs about soil structure and facilitation of air and water flow	R
Soil pollution test on Collembolans	% mortality	Based on Collembolans, it informs on levels of soil pollution	A
Soil texture (Descriptor)	% sand, % clay, % loam	Soil texture is the relative proportions of sand, silt, or clay in a soil.	R
Tea Bag Index	decomposition rate (k) $g\ g^{-1} yr^{-1}$	Informs of soil capacity to decompose organic materials	A
The Bait-Lamina test	% of baits eaten	Informs on soil biological activity	A
Total abundance of microarthropods	number of $ind.cm^{-3}$	Numbers, composition and size of invertebrate community within the soil	A
Total abundance of nematodes	number of ind.100 g^{-1} dry soil	Numbers, composition and size of the nematode community	A
Total microbial biomass by Chloroform Fumigation-Extraction	$\mu gC.g^{-1}soil$	Informs about total C allocated to microbial biomass	M
Total microbial biomass catabolic ability by Multiple substrate-induced respiration (MSIR)	$\mu gCO_2/g.h$	Refers to the activity capability profile of the total soil community, or the active fraction of total microbial biomass	R
Total microbial biomass DNA (total)	mgC kg^{-1} soil	Informs on soil microbial biomass amount	A
Total N in soil	mg g-1		M

Total predicted soil loss	t $ha^{-1} yr^{-1}$	Informs about simulated erosion	A & R
Total SOC simulated	g C kg of soil $^{-1}$	Simulates soil C's response to changes in management practices, land use and/or climate conditions and simulates changes in SOC stocks	A & R
Water holding capacity (simulated)	% water/volume of saturated soil	The ability of soil to store water against the force of gravity	A & R
Water Infiltration	mm h^{-1}	SWI represents the capacity of the soil to let water drain into the soil	R
Crop yield (simulated)	t ha^{-1} yr^{-1}	Fundamental for food security estimation	R
Stability in crop yield over time (simulated)	Δ t ha^{-1} yr^{-1}	Fundamental for food security estimation and farm profitability	R

*Table 15: Presentation of the indicators that are tailored to evaluate the NBS impact assessment for forestry monitoring. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; R: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative.*

Indicator	Unit	Description	Climate strategy
Total carbon stored in vegetation	kg ha-1 y-1	Total Carbon Stored in Vegetation refers to the amount of carbon sequestered in the biomass of plants, including trees, shrubs, and other vegetation, within a given area.	M
Carbon storage score	kg day-1	Carbon Storage Score is a metric used to quantify the capacity of a forest or vegetation type to store carbon, taking into account factors like biomass, forest density, and growth stage.	M
Abovegroun d tree biomass	t ha-1	Aboveground Tree Biomass refers to the total mass of living tree material above the soil, including the trunk, branches, leaves, and reproductive parts.	M
Flammability Index	unitless	The Flammability Index measures the susceptibility of vegetation or forest areas to catch fire, considering factors such as moisture content, fuel type, and weather conditions.	R
Total vegetation cover	%	Total Vegetation Cover refers to the proportion of land area covered by plant life, including trees, shrubs, grasses, and other vegetation.	R
Woody vegetation cover	%	Woody Vegetation Cover refers to the proportion of land area covered by woody plants, including trees, shrubs, and other perennial woody species.	R
Non-woody vegetation cover	%	Non-Woody Vegetation Cover refers to the proportion of land area covered by herbaceous plants, such as grasses, herbs, and other non-woody species.	R

Forest development	No. of diameter classes	Measure of the Different Stages of Forest Stand Development, based on the number of diameters classes, refers to a classification system used to assess the age and growth stage of a forest by categorizing trees into diameter classes (e.g., small, medium, large). T	R
Tree biomass stock change	t ha $^{-1}$ year $^{-1}$	Tree Biomass Stock Change refers to the variation in the total biomass of trees in a specific area over a defined period, reflecting growth, mortality, or harvest activities.	M
Quantity of dead wood per unit area	m^3 ha^{-1}	Quantity of Dead Wood per Unit Area refers to the amount of dead wood, including fallen trees, branches, and logs, present in a specific area of forest.	R
Carbon uptake	tC ha^{-1} $year^{-1}$	Carbon Uptake refers to the amount of carbon which goes through the process by which plants, trees, and ecosystems absorb carbon dioxide (CO_2) from the atmosphere through processes like photosynthesis.	M
The total amount of carbon stored in vegetation	t ha^{-1}	Total Amount of Carbon Stored in Vegetation refers to the total carbon sequestered in the biomass of plants, including trees, shrubs, and other vegetation, within a specific area.	M
Allometric forest models of carbon sequestration	t C ha^{-1} $year^{-1}$	Allometric Forest Models of Carbon Sequestration refers to models that estimate forest carbon stocks and sequestration potential by correlating tree biomass and carbon content with data collected through Light Detection and Ranging (LiDAR) technology.	M
Carbon sequestration rate	t C ha^{-1} $year^{-1}$	Carbon Sequestration Rate by Tree Species refers to the rate at which different tree species absorb and store carbon over a specified period, typically measured in tons of carbon per hectare per year (tC/ha/year)	M
Fossil Fuel Replacement	kj ha^{-1}	Quantification of Biomass Energy Potential: Determine the amount of biomass (e.g., wood chips) that can be converted into bioenergy, replacing fossil fuels.	M
Parasitic plant biomass removed	t/ha	Biomass of parasitic plant species removed	A
Individuals of parasitic plant species removed.	Number ha^{-1}	Individuals of parasitic plant species removed	A

Table 16: Presentation of the indicators that are tailored to evaluate the NBS impact assessment for the stormwater regulation and water quality and quantity. These indicators are categorized with respect to their contribution to Climate

*strategy, using the following terms, **ER**: Enhance Resilience; R: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative.*

Indicator	Unit	Description	Climate strategy
Biological quality of groundwater/ surface waters	maximum, good, moderate, poor, bad	This refers to the health of aquatic ecosystems, as assessed by the presence and abundance of various organisms, such as bacteria, invertebrates, and fish species, in groundwater or surface water bodies.	M
Blue City Index	%	The Blue City Index is a tool used to assess the sustainability and effectiveness of urban water management systems, focusing on the integration of water-related policies and practices in cities. It evaluates various factors such as water consumption, water quality, stormwater management, and the promotion of water-sensitive urban design, typically providing a score or ranking to guide cities in improving their water management strategies.	ER
Combined sewer overflows (CSO)	No./device/year	This is the ratio between the number of yearly CSOs occurrences which have been registered by the utility and the number of CSO devices of the system, at the assessment date of the assessment year.	ER
Depth to groundwater	m	This refers to the vertical distance from the ground surface to the top of the groundwater table.	ER
Desalinated water/total water withdrawal	%	This refers to the proportion of water sourced from desalination processes compared to the total amount of water withdrawn for use in a given area.	A
Direct emissions to water	g L-1	*Can be evaluated with water quality indicators for each water quality parameter (see other specific indicators)	M
Drinking water consumption (DWCPC)	L/(capita.day)	The drinking water consumption per capita is a measure of how effectively water is used by the inhabitants. Thus, it is also an indirect measure of the number of water-saving products and installations that are installed and used by inhabitants. Its assessment requires the value of the annual drinking water production and consumption which includes water used for industry, public use, leakages and other unaccounted-for water use.	M
Ecological status	very good, good, moderate, poor or poor status.	Ecological status is defined as an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters. For ecological status, a distinction is made between very good, good, moderate, poor or poor status. It takes into account quality elements of rivers, lakes, transition water or coastal water. These types are hydromorphological, biological or physical-chemical elements.	M

Environmental flow requirement compliance rate (EFRCR)	%	The environmental lower limit for water flow in a stream or river is defined by the EFR (Environmental Flow Requirement).	ER
Groundwater exploitation index	%	The Groundwater Exploitation Index is an indicator used to assess the sustainability of groundwater use by comparing the volume of groundwater extracted to the volume of groundwater that is naturally replenished (recharge rate).	M
Inundation risk for critical urban infrastructures (probability-economic)	%	Probability of a reduction of inundation risk for critical urban infrastructures based on earth observation and remote sensing approaches	ER
Physical access to drinking water supply for households and small businesses (PHConnect)	%	The metric reflects the proportion of households and small businesses connected to service (PHconnect). It is assessed as the percentage of households and small businesses connected to the waterworks over the total x 100; it also includes mixed/commercial properties and multiple household properties, e.g., blocks or flats.	I
Physical access to drinking water supply in public spaces for quality of life (PWA)	No./km^2	This is a density index defined as the total number of operational physical access points to water supply in public spaces (public drinking water fountains, cooling fountains, etc.) of a given area. A fountain or other point of public consumption must be considered “non-operational” when it is not possible to provide water to consumers due to physical deficiencies (e.g., broken taps, and broken pumps).	I
Physical access to water for irrigation (PAConnect)	%	The access to water for agriculture or gardening reflects the level of sustainable practice adopted for irrigation.	I
Physical access to water supply for industrial use (PIConnect)	%	The physical access to the water supply rate reflects the accessibility in terms of the water supply network and a physical connection to the system as required by industries.	I
Piezometric level fluctuation	m or %	It evaluates the increase or decrease of the piezometric level of groundwater.	I
Quantitative status of groundwater/surface water	good or poor	This refers to the availability or volume of groundwater or surface water in a specific area, often assessed by measuring water levels, flow rates, or storage volumes.	M

Rainwater or greywater is used for irrigation purposes	m^3/y	*Not needed, could be considered in Reclaimed Water in non-potable Uses (RWnpU) indicator if rainwater or greywater are previously treated	A
Safe drinking water (CtotalDW)	%	Percentage of compliance with drinking water quality standards.	ER
Surface area of restored and/or created wetlands	Ha	water nexus?	ER
Treatment capacity utilization (TCU)	%	The percentage of treatment capacity used in the period of highest production is computed as the ratio between the daily average wastewater flow of the 30 consecutive days with the highest inflows and the daily treatment capacity.	ER
Waterbody self-purification (SPNPC)	%	Measures the self-purification of nutrients in a water body in relation to the total load by nutrient entry to the water body on an annual time frame.	ER
Water dependency for food production	m^3	This refers to the amount of water required for agricultural activities to produce food, including irrigation, livestock, and crop water needs.	M
Water exploitation index, plus (WEI+)	%	The WEI+ aims to illustrate the percentage used of the total renewable freshwater resources available in a defined territory (basin, sub-basin etc.) for a given time step (e.g., seasonal, annual). WEI+ is a 'state' indicator (DPSIR). Its legislative reference is the Water Framework Directive. WEI+ is linked to SDG 6, indicator 6.4.2 (level of water stress).	M
Water Footprint (WFP)	$m^3\ m^{-3}$	Water footprint associated with direct and indirect use of water for the consumption of 1m3 of drinking water, production of reclaimed water and/or the treatment of 1m3 of wastewater. WFP is an indicator of direct and indirect freshwater resource appropriation. Directly used water is the amount used in the production/treatment, while indirect is the amount used in producing products, processes, systems, etc. that is used in the production/treatment of the product. It follows the Water Footprint Network (WFN) methodology.	M
Water Intensity (WI)		Water Use Intensity– is all water sources divided by the building surface, including outdoor surface. The ratio between water intake and a defined unit of production.	M
Water Security (WS)		The urban water security index includes water supply coverage, wastewater treatment and urban flooding. In addition to these	Enhance d

		sub-indices, several adjustment factors are used in order to represent urban growth rate and river basin health.	resilienc e
Water Use Efficiency Index	number	This is an indicator that measures the efficiency of water use in relation to the output of a given process, such as agricultural production, industrial activity, or urban water management.	Mitigati on

*Table 17: Presentation of the indicators that are tailored to evaluate the NBS impact assessment for heat mitigation. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; R: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative.*

Indicator	Unit	Description	Climate strategy
Accessibility of 3 trees from each home	Mean number of trees from each home	Following the 3-30-300 rule, everyone should be able to see at least 3 trees from their home. Use satellite imagery and Geographic Information Systems (GIS) to map tree locations and their visibility from residential buildings. 3D modelling can help simulate viewsheds to determine if at least three trees are visible from various vantage points. The measurement should be done once per year to track the differences.	M
Accessibility of 30% tree cover in every neighbourhoo d	Mean tree cover % from each neighbourho od	Following the 3-30-300 rule, there should be 30% tree canopy cover in every neighbourhood. Utilize GIS tools to overlay tree canopy data (e.g. LIDAR or NDVI) on neighbourhood maps. Calculate the total canopy area and divide it by the total land area to get the percentage cover. The measurement should be done once per year to track the differences.	M
Accessibility of urban green spaces (ensure the "300" part of the 3-30-300 rule)	Mean m to the first green space from each home.	Following the 3-30-300 rule, each individual should live within 300 m of a high-quality green space. To obtain the data you should map all green spaces in the city using GIS. Then, create buffer zones of 300 meters around each green space and analyse the coverage to ensure every residence falls within one of these buffers. The measurement should be done once per year to track the differences.	M
BAF – Biotope Area Factor (Huang et al., 2015)	0-1	The BAF is calculated by dividing the amount of surface area available for nature and vegetation by the total surface area considered. Each type of soil/ground cover/land use is affected by a coefficient related to its potential for vegetation growth & nature implementation (e.g. sealed surface = 0; semi-permeable = 0.3; green wall = 0.5; green roof = 0.7; in-ground plantations = 1). Thresholds and goals can then be determined based on the expected performance or current land use / urban planning objectives (e.g. the City of Berlin expects BAF to be produced for each new project – the result must be between 0.3 and 0.6, depending on the project's nature). The BAF has values between 0 and 1. It increases with in-ground planted areas.	ER

Bird species richness	Number	A high number of bird species typically indicates a healthy and diverse ecosystem. Birds often occupy various niches, and their presence reflects the availability of different habitats and resources. Bird watching and listening to bird songs enhance the aesthetic value of green spaces, providing recreational opportunities and improving the quality of life for urban residents. Interactions with nature, including bird watching, are known to reduce stress, anxiety, and depression, contributing to overall mental well-being. Birds provide an accessible way to engage the public in environmental education, raising awareness about biodiversity and conservation issues.	ER
CAQI – Common Air Quality Index	0-100	The CAQI is a number on a scale from 1 to 100, where a low value means good air quality and a high value means bad air quality. It integrates measurements for NO_2, PM_{10} and O_3 ($PM_{2.5}$ is optional)	A
CGS - Connectivity of green spaces (Direction Régionale de l'Environnement Nord-Pas-de-Calais. 2008; AUAT., 2015)	m (The straight-line distance between two green spaces)	This indicator enables us to assess natural habitats best connected to each other in the study area. It takes into account the fragmentation of the habitat. Thus, this indicator will help to know where to focus efforts, where to improve the connectivity (where it is the lowest) and where to maintain green spaces in priority (where connectivity is the highest because these areas are more favourable to species) → decision-making tool. The efforts to be made will depend on the objectives of each city.	A
Change in tree cover % change in 5 years	%	Measures the percentage of tree coverage and its change over a five-year period.	ER
City Biodiversity Index	Rank	The City Biodiversity Index (CBI) - also known as the Singapore Index on Cities' Biodiversity (SI) - is a self-assessment tool for cities to evaluate and monitor the progress of their biodiversity conservation efforts against their own individual baselines.	A
Food production in urban allotments and NBS	t/ha/y	Food production in urban allotments is a valuable component of nature-based solutions (NBS) due to its wide-ranging benefits for urban environments and communities (e.g. enhancing food security, promoting sustainability, and providing ecosystem services...)	A
Green and Blue Space Proportion	% in m2	This indicator represents the ratio of the natural areas per total area. The different input parameters can be derived from land use and land cover geodatabases at different scales.	ER

Green area surface by neighbourhood/ Neighbourhood inhabitants	m2/inhabitant	The World Health Organization recommends that towns and cities should have at least 10-15 m^2 of green space per inhabitant.	M
Green area sustainability		Green area sustainability based on the Urban greening method	ER
Heat-related discomfort	°C	The universal thermal climate index (UTCI) is a human biometeorology parameter that is used to assess the linkages between the outdoor environment and human well-being. Thermal comfort indices describe how the human body experiences atmospheric conditions, specifically air temperature, humidity, wind and radiation.	M
Modelled O3, SO2, NO2 and CO capture removal by vegetation	kg/ha/y	Estimation of PM removed by the green surfaces of the NBS. Tiwary method", map air purification using spatially explicit data on ecosystem types and characteristics (particularly LAI), and pollution distribution, Forest Inventory Analysis.	M
Noise pollution in Sound pressure level	dB	In the context of NBS, measuring noise pollution helps assess the effectiveness of green infrastructure in mitigating urban noise. A baseline measurement should be done before implementing an NBS and then comparing it to the post-implementation. It can also be measured as the equivalent continuous noise level, Day-night average sound level, Day-evening-night average sound level or peak noise level.	M
Number of invasive alien species	Number	"Invasive Alien Species (IAS) are animals and plants that are introduced accidentally or deliberately into a natural environment where they are not normally found, with serious negative consequences for their new environment. They represent a major threat to native plants and animals […]"http://ec.europa.eu/environment/nature/invasivealien/index_en.htm)	ER
Number of native species	Number	A high number of native species typically indicates a healthy and functioning ecosystem. Native species are adapted to local conditions and contribute to ecological balance. Biodiverse ecosystems are more resilient to disturbances such as pests, diseases, and climate change. Native species play crucial roles in maintaining these resilient ecosystems.	ER
Non-native species	Number	Non-native species can have both positive (i.e. If it's not invasive species) and negative impacts, depending on various factors such as their behaviour, ecological role, and how they interact with native species and ecosystems.	ER

Perceived quality of urban blue-green spaces	various	Perceived quality of urban blue-green spaces (accessibility, amenities, natural features, incivilities and recreational facilities)	A
Proportion of road network used by pedestrians and/or bicyclists	%	The proportion of the road network dedicated to pedestrians and bicyclists is a vital metric in the context of nature-based solutions. It promotes sustainable mobility, enhances public health and safety, supports environmental goals, provides economic benefits, improves social equity, and aids in effective urban planning. By prioritizing infrastructure for non-motorized transport, cities can create healthier, more sustainable, and more resilient urban environments.	A
The ratio of open spaces to build form (ratio)	Number	This ratio provides insight into the balance between natural and constructed environments within urban areas, which has significant implications for ecological, social, and economic benefits (e.g. more habitats for various species, promoting biodiversity within urban areas, climate regulation, water management, recreation and wellbeing)	ER
Shannon Diversity Index	Number	The measure of species diversity related to species richness	A
Shannon Evenness Index	Number	The measure of species diversity related to species equality	A
Temperature	°C	Projection of the temperature reduction	M
Temperature reduction in urban areas ECS	°C	The reduction of the heat island effect of the entire city is the wrong scale (impossible to tie to ECS) but could maybe measure the "microclimate" of the ECS compared with nearby urban areas.	M
Tree shade for local heat reduction	m^2	Measure the impact of trees, on mitigating urban heat. This indicator could be relevant in some ECS - an increase in edible trees over other crops.	M
Tree species diversity	Number of different plant species	The idea is that no species should exceed 15% (to foster biodiversity but also to decrease the probability of pests and allergies...)	ER
Urban Heat Island (UHI) effect	°C	The difference in temperature between city centres and rural/suburban areas. Informs about the inadequate design of street shapes and use of materials and heat derived from urban energy transformations.	M
Volatile Organic Compounds (VOC) Concentration	$\mu g/m^3$ / ppb	Continuously monitor VOC concentrations and observe changes over time.	A

*Table 18: Presentation of the indicators that are tailored to evaluate the NBS impact assessment for energy consumption. These indicators are categorized with respect to their contribution to Climate strategy, using the following terms, **ER**: Enhance Resilience; R: Resilience; **M**: Mitigation; **A**: Adaptation; **A & R:** Adaptation on Resilience; **I**: Indicative.*

Indicator	Unit	Description	Climate strategy
Adaptive Capacity	Yes/No/ Likert scale	The ability of the energy system to adapt to changing conditions and recover from disruptions	M
Air pressure	Pa	Pressure of air	M
Anthropogenic heat (traffic flow)	J	The heat produced by humans	M
Avoided emissions from energy savings	t CO2e/y	Estimates the GHG emissions reduction due to the decrease in energy consumption.	M
Avoided GHG emissions in buildings	t CO2e/y	Estimates the GHG emissions reduction in energy consumption for buildings.	M
Biofuel share in transportation	%	The percentage of biofuels (e.g., bioethanol, biodiesel, biogas) used in transportation. It is calculated with the following equation. Biofuel Share (%)=(Total Volume of Transportation F uels/Volume of Biofuels Consumed)×100	M
Biogas composition	%	Biogas constituents	M
Brightness index (BI)	-	It is measured on a scale from 1 to 10, where 1 is a grey, dark, dismal day and a 10 is a very bright day with blue sunny skies, no clouds, no pollution and a high level of glare at sunrise and sunset.	M
CO2 emission reduction	% in tons	Reduction in direct (operational) CO2 emissions achieved by the project.	M
Carbon emissions due to treatment of runoff water (combined sewers)	t CO2e/y	Estimation of the CO2 emissions reduction due to rainwater runoff treatment.	M
Cooling energy saving on cloudy days (rate)	$kWh/m^2 \cdot day$ AND %	Cooling energy saving on cloudy days due to NBS (green wall or roof)	M
Cooling energy saving on sunny days	$kWh/m^2 \cdot day$ AND %	Cooling energy saving on sunny days due to NBS (green wall or roof)	M
Cumulative energy demand	MJ/kg food	Cumulative energy demand (CED) of a product system of energy use throughout the life cycle.	M
Decarbonization rate	%	How much of the electricity mix is renewable	M
Decrease in energy consumption due to	%	Decrease in energy consumption due to a decrease in transportation	M

a decrease in transportation.			
Electricity use in agriculture	kWh/kg food	Energy use in agriculture points to the energy-food relation by illustrating the total energy demand per kg of food product	M
Embodies energy content of waste biomass	MJ/kg of waste biomass	What is the calorific value of agri-waste	M
Energy Consumption per Capita	MJ/person	Total energy consumption divided by the population	M
Energy Cost per Calories of Production	€/calories food	Cost of energy consumed per unit of agricultural output (e.g., cost per ton of crop).	M
Energy Cost per Unit of Production	€/kg food	Cost of energy consumed per unit of agricultural output (e.g., cost per ton of crop).	M
Energy input	MJ/kg food	Direct and indirect energy inputs	M
Energy Intensity	kWh/€	Energy consumption per unit of national or local GDP	A
Energy Intensity of Water Supply	kWh/m^3 clean water	Energy consumption per cubic meter of water supplied	M
Energy mass productivity	MJ/ha	Evaluate the efficiency of crop yield (ha) against energy used for production (per ha) at a particular time (t)	M
Energy performance	MJ	The energy performance of a building is a critical factor in monitoring how much energy the building consumes, as well as the extent of the building's emissions of polluting greenhouse gases into the environment.	M
Energy Return on Investment (EROI)	%	The ratio of energy gained from a system compared to the energy invested in its creation and maintenance.	M
Energy Savings from Efficiency Measures based on Calories of Production	€/calories food	Reduction in energy costs due to implemented energy efficiency measures.	M
Energy Savings from Efficiency Measures based on Unit of Production	€/kg food	Reduction in energy costs due to implemented energy efficiency measures.	M
Energy security	%	Fair access to sustainable and affordable sources of energy guarantees human welfare.	M

Energy Storage Capacity	kWh	Amount of energy that can be stored for later use	M
Energy use in agriculture	%	Energy use in agriculture points out the energy-food relation by illustrating the percent ratio of the energy consumed for agricultural purposes to the total energy demand.	M
Energy use in agriculture	MJ/kg transported food	Energy use in transportation regards the energy-food relation by illustrating the total energy demand per kg of transported food product	M
Energy use in agriculture	MJ/kg protein content of food	Energy use in agriculture points to the energy-food relation by illustrating the total energy demand per kg of protein in food product	M
Enhanced vegetation index (EVI)	%	Landsat Enhanced Vegetation Index (EVI) is similar to the Normalized Difference Vegetation Index (NDVI) and can be used to quantify vegetation greenness. However, EVI corrects for some atmospheric conditions and canopy background noise and is more sensitive in areas with dense vegetation.	M
Evapotranspiration (plants in NBS)	kg water/m^2 NBS surface	Evapotranspiration is the sum of all processes by which water moves from the land surface to the atmosphere via evaporation and transpiration.	M
Evapotranspiration rate (ETo)	mm	To represent the evapotranspiration rate from a reference surface, not short of water. A large uniform grass field is considered worldwide as the reference surface. The reference crop completely covers the soil, is kept short, well-watered and is actively growing under optimal agronomic conditions.	M
Geometry, size, shape, area & height	m	Quantify the physical dimensions of NBS and verify its efficiency considering the deployment on a specific ecosystem.	M
Greenness index (VGI)	%	The Greenness Index, specifically the Visible Greenness Index (VGI), is a measure of the degree of greenness from a human visual perspective.	M
Grid Stability and Reliability	# of incidents	Frequency and duration of power outages and grid disturbances	M
Heating energy saving rate	%	Avoided energy use due to NBS (green wall or roof)	M
Increased efficiency of resources consumption	% in tons	Reduction in material consumption of the project	A
Indoor Air Quality Improvement	ppm NO_x, SO_2, $PM_{2.5}$	Reduction of air pollutants	M

Indoor temperature reduction	°C	Indoor temperature reduction due to green wall	M
Industrial Energy Efficiency	MJ/unit	Energy consumption per unit of industrial output	M
Job Creation	# of jobs	Number of jobs created as a result of implementing energy and NBS projects	M
kWh savings per year	kWh/y	Reduction of electrical energy used.	M
Land-use types	Classification system: Urban, Agricultural, Forest, Wetland	Types of used land	M
Land-use/land-covers (LULC)	%	Land Use / Land Cover (LULC) generally refers to the categorization or classification of human activities and natural elements on the landscape within a specific time frame based on established scientific and statistical methods of analysis of appropriate source materials	M
Leaf area density (LAD)	%	The leaf area density (LAD) distribution is a key index for characterizing the vertical and horizontal crown structures and is defined as the total one-sided leaf area per unit volume	M
Leaf area index (LAI)	-	Leaf area index (LAI) is a dimensionless quantity that characterizes plant canopies. It is defined as the one-sided green leaf area per unit ground surface area (LAI = leaf area/ground area, m^2/m^2) in broadleaf canopies.	M
Leaf colour and thickness	Qualitative-quantitative scale (e.g., "Dark green, 0.5 mm")	Changes in leaf colour	M
Life cycle stage energy consumption	kWh	Operational electricity consumption or use stage electricity consumption.	M
Local Climate Zones (LCZ)	LCZ Codes (1–10, A–G)	Local Climate Zones (LCZ) form a systematic classification scheme that is used nowadays for zoning and categorization of the internal structure of urban areas for various applications including urban climatology	M
Mean radiant temperature (Tmrt)	ºC	The mean radiant temperature (MRT) is based on the principle that the net exchange of radiant energy between objects is approximately proportional to	M

		their temperature difference multiplied by their ability to emit and absorb heat (emissivity)	
CH_4 content of biogas generation due to wastewater treatment	%	The percentage of Methane (CH_4) in the total volume of biogas produced during the anaerobic digestion. It is calculated as: Methane Content (%)=(Total Volume of Biogas Produced/Volume of Methane in Biogas) ×100	A
Morbidity, Mortality and Years of Life Lost due to poor air quality	years	Reduction in years of life (y) due to premature mortality in comparison with standard life expectancy	M
NDVI	%	Normalized difference vegetation index (NDVI) is a simple graphical indicator that is often used to analyze RS measurements and assess whether the target being observed contains green health vegetation or not.	M
Outdoor air Quality Improvement	ppm NOx, SO_2, $PM_{2.5}$	Reduction of air pollutants in outdoor space (e.g., the gardens of DEMO 9)	M
Percentage of biogas upgrade to bio-methane	%	How much on-site generated biogas is upgraded	M
Plant solar transmissivity	D	Transmissivity, t, is the fraction of heat intensity transmitted that corrects the effect of atmospheric absorption for distances	M
Plant species	-	Count the differences in plant species	M
Reduction in annual final energy consumption	% in kWh	Change in annual final energy consumption due to the project for all uses and forms of energy	M
Reduction in lifecycle CO_2 emissions	% in tons	Reduction in lifecycle CO_2 emissions achieved by the project	M
Reduction in lifecycle energy use	% in kWh	Reduction in life cycle energy use achieved by the project (%)	A
Reduction of embodied energy of products and services used in the project	Likert	The extent to which measures have been taken to reduce the embodied energy of products used in the project.	M
Reduction of energy demands	t C year-1	The energy not consumed for heating and cooling buildings can be accounted for with an estimation of the reduction of CO_2 emissions.	M
Renewable energy produced in NBS	kWh/y	Measures the amount of renewable energy that was produced due to the deployment of NBS.	M

Scope 2 emissions	kg CO_2 eq.	Scope 2 emissions are indirect GHG emissions associated with the purchase of electricity, steam, heat, or cooling	A
Soil temperature (sub-surface)	ºC	Temperature of soil	M
Solar absorption capacity	J/m^3	Solar absorption is that portion of total solar energy neither transmitted nor reflected. Since solar transmittance and solar reflectance are measured directly	M
Solar electric footprint	m^2	Land needs for the primary energies that support the final demand of a defined human population.	M
Solar radiation	W/m^2	Solar radiation, often called the solar resource or just sunlight, is a general term for the electromagnetic radiation emitted by the sun. Solar radiation can be captured and turned into useful forms of energy, such as heat and electricity, using a variety of technologies	M
Surface albedo	%	Albedo is the fraction of light that a surface reflects. If it is all reflected, the albedo is equal to 1	M
Surface emissivity (ε)	-	Thermal emissivity ε is the efficiency with which a surface emits its stored heat as thermal infrared (TIR) radiation	M
Surface permeability	m_2	Permeable surfaces (also known as porous or pervious surfaces) allow water to percolate into the soil to filter out pollutants and recharge the water table.	M
Surface temperature (Tsurf)	ºC	Temperature of surfaces	M
Sustainable Energy Practices	%	Adoption rate of sustainable energy practices in the water and food sectors	A
t C/y savings per year	ton C/year	Carbon savings from reduced energy consumption will be calculated by conversion factors given by the Building Energy Performance Regulation (BEP, 2017).	M
Thermal conductivity	W/(m·K)	Thermal conductivity is defined as the ability of a material to conduct heat from one side to the other.	M
Thermal energy for photosynthesis	J	vegetation absorbs thermal energy for photosynthesis and acts as a shadow device, protecting the soil from solar radiation	M
Thermal insulation	W/(m2·K)	Thermal insulation is the set of insulating materials and construction techniques whose installation reduces heat transmission between two spaces	M
Total CO_2 emissions	kg CO_2	Assessment of the total amount of CO2 emissions reduced.	M

Total greenhouse gas emissions per year	t CO2e/y	Assessment of the total amount of GHG emissions reduced per year.	M
Type of foliage	%	Percentage Coverage of foliage	M
Vegetation, impervious (ISF), building and water fractions	%	An impervious surface ratio is the relationship between the total impervious surface area on a site and the gross land area	M
Volumetric density of buildings	Number of buildings/m^2	Density is the number of developed units in a specific area of land	M
Wall surface temperature increase (in winter)	°C	The difference in the wall surface temperature between the baseline condition and the scenario with NBS. It is calculated as follows: $\Delta T_{Wall} = T_{Wall\ (NBS)} - T_{Wall\ (Baseline)}$	M
Wall surface temperature reduction (maximum)	°C	The total temperature reduction due to the deployment of the green walls.	M
Water Consumption for Energy	m^3/kWh	Volume of water consumed and not returned to the source for energy production processes	M
Water Withdrawal for Energy	m^3/kWh	Volume of water withdrawn for energy production (e.g., cooling in power plants, biofuel production).	M
Wetness Index (WI)	%	The wetness index (WI) is a geographical parameter that quantifies the local wetness and precipitation-evapotranspiration offset of a certain area	M
Wind direction (Vd)	N, S, NE, SE, E, etc.	Direction of wind	M
Wind velocity (Va)	m/s	Wind speed	M
RES Units Integrated and Capacity	% and MW	The combined energy capacity of the deployed Renewable Energy Sources (RES).	M
Sustainable Energy Practices	kWh	Kilowatt-hours (kWh): For energy saved through sustainable practices over a given period.	