Deliverable 2.2: *First report on environmentally sustainable, resilient forest models*

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List of acronyms and abbreviations

ACRONYM	Description
C3S	Copernicus Climate Change Service
CCTV	Closed-circuit television
CDS	Climate Data Store
CEMS	Copernicus Emergency Management Service
CLMS	Copernicus Land Monitoring Service
CMIP	Coupled Model Intercomparison Project
CORDEX	COordinated Regional Downscaling Experiment
CSA	Coordination and Support Action
DBH	Diameter at Breast Height
DoA	Description of Action
DSS	Decision Support System
DX.Y	Deliverable X. Y (X refers to the WP and Y to the deliverable in the WPX)
FIPAS	Fire prevention and awareness support Mobile application
GIS	Geographical Information System
MVP	Minimum Viable Product
OS	Operational Scenarios
TX.Y	Task, where X is the WP number and Y the Task number within WPX
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
WP	Work Package

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Table of Contents

Index of figures

Index of tables

Executive Summary

The purpose of this deliverable "First report on environmentally sustainable, resilient forest models (D2.2)" is to consolidate and report on the activities carried out in WP2, across T2.1 to T2.5. within Work Package 2 (WP2).

Task *Stakeholder consultation through participatory process (T2.1)* and task *Functional requirements (T2.2)*, under the leadership of project partner TUZVO, already contributed to D2.1 released at the end of May 2022 in M8. The objective of task T2.1 was to develop and report on a systematic procedure to engage stakeholders interested in mitigating the number and impact of wildfires. The task T2.2 aimed at finalizing the functional requirements of the SILVANUS platform based on the scenarios identified through engagement in T2.1 for all phases of wildfire and forest management services - A (prevention and preparedness), B (detection and response), and C (restoration and adaptation). Guidelines for questionnaire preparation, presentation to stakeholders, and evaluation were produced to enable partners in describing existing measures, processes, technologies, and services within the above described three phases (A/B/C) and in improving them under representative Operational Scenarios (OS), as well as to compile a Database of requirements in terms of possible data, models, and tools expected to be available from the SILVANUS platform.

The task *Forest landscape models for wildfire threat assessment (T2.3*) aims at reviewing, studying, and selecting the forest landscape models/DSSs, and related specifications, to be adopted in SILVANUS pilot sites, identifying and describing approaches that incorporate multiple spatiotemporal processes such as biotic and abiotic disturbances, as well as human management and interventions. This will lead to a refined definition of the scope of demonstration activities within Pilots. Successively, the steps to arrange selected forest models/DSSs as practical tools in Pilots (through the project's Platform) will be conducted, aiming to be progressively ready in early 2023. T2.3 is strongly connected to T2.4 (*Climate sensitive forest models for impacts on forest management*), where a particular category of forest models is reviewed, classifying - under several complexity criteria - those approaches allowing to simulate the growth dynamics of forest ecosystems considering combined human managements and climate drivers. To this aim, also a quick scan of datasets to rely on as possible sources of input data and parameters was conducted and is also reported.

To complement the above data collection and review, the goal of the T2.5 (*Forest resilience from historical case studies*) is to gather and analyze information from the historical reports, datasets, and other types of sources available on past forest fires across the project's demonstration sites, covering a wide range of triggering causes. Each of the Pilots will be also analyzed exploiting the Earth Observation, from Copernicus and other data portals, to map the transformation of forest landscape after the spread of analyzed wildfires.

It is noteworthy that the Tasks contributing to this D2.2 are strictly interacting. For example, T2.1 and T2.2 together feed T2.3, T2.4, and T2.5 especially in terms of Pilot sites' characteristics and requirements of data, tools, and technologies. In turn Task 2.5 will complement Pilots' information from T2.1/T2.2 with a collection of data about past fire events, particularly useful for models' calibration and validation purposes in T2.3 and T2.4. Further, these two tasks strongly collaborate as the latter will use models' definitions and inventory methodology from the former deepening the focus on climate influence on forests: Finally, T2.4 and T2.5 can mutually exchange information related to forest, tree, soil, landscape, and climatic characterization, merging project-derived and existing sources.

Moreover, D2.2 is a first release of D2.4 *Report on environmentally sustainable, resilient forest*, to be finalized when 80% of WP activities, and more than half of project duration, will be completed.

The Table below summarize the work conducted per Task involved until M11.

T2.1 and T2.2	Task 2.1 developed and reported on a systematic procedure to engage stakeholders, from questionnaire preparation to presentation of them to stakeholders to evaluation of received answers. Task T2.2 aimed at finalizing the functional requirements (data, models, tools) of the

	SILVANUS platform based on the scenarios identified through engagement in T2.1 for all phases of wildfire and forest management services.
T2.3	T2.3 defined criteria to characterize and rank models, tools and DSS to adopt in SILVANUS
T2.4	T2.4 is a further focus from T2.3 on climate sensitive forest models and possible input datasets.
T2.5	T2.5 defined criteria to collect information on past wildfires (predisposing and triggering factors) across Pilot sites.

1. Introduction

This deliverable aims at describing the activities completed in WP2 of SILVANUS project when slightly more than one third of WP2 duration has been achieved, and 25% of the whole Project duration. The Deliverable, and the WP2 as a whole, acts as preliminary support to the activities carried out in WP3, WP4 and WP5 related to Phase A (prevention and preparedness) and B (detection and response), and more indirectly to WP6 and WP7 on Phase C (restoration and adaptation), while also exchanging feedbacks with WP8 and WP9 about the project's platform and the necessary demonstration activities through Pilots. A final release of the Deliverable (D2.4) is expected in Month 24 when the WP2 activities will be at 80% of their duration and when more consolidated outcomes from the five contributing Tasks will be achieved.

Indeed, the Deliverable is fed by the following Tasks and/or Deliverables closed/in progress:

- systematic methodology for participatory process (D2.1, fed by T2.1 and T2.2, led by partner TUZVO);
- the review of forest landscape models for the pilot demonstrations sites (T2.3, led by partner AUA);
- the climate sensitive forest models (T2.4, led by partner CMCC);
- historical review of forest resilience to wildfires (D2.1, fed by T2.5, led by partner ASSET).

Therefore, this Deliverable is organized into four main sections according to the above components, with also clarifications of how possible cooperation among Tasks are conducted and managed.

Indeed, the Tasks mentioned are not disconnected from one another. T2.1 and T2.2 together feed T2.3, T2.4, and T2.5 especially in terms of Pilot sites' description and requirements of data, tools, and technologies. In turn Task 2.5 will complement Pilots' information from T2.1/T2.2 with a collection of data about past fire events, particularly useful for models' calibration and validation purposes in T2.3 and T2.4. Furthermore, these two tasks strongly collaborate as the latter will use models' definitions and inventory methodology from the former, deepening the focus on climate influence on forests. Scientific literature will support such review starting from robust comparative analyses and assessments across existing models, tools, services[1,2,3,4,5]. Finally, T2.4 and T2.5 can mutually exchange and complement data related to forest, tree, soil, landscape, and climatic characterization, merging project-derived and existing sources.

All the Tasks are expected to produce scientific papers and establish collaboration with Coordination and Support Action (CSA) projects funded under the same Horizon 2020 Call "*Preventing and fighting extreme wildfires with the integration and demonstration of innovative means*".

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[1] Segura M., Ray C., Maroto C. (2014) Decision support systems for forest management: A comparative analysis and assessment. Computers and Electronics in Agriculture, 101, 55-67. Doi: 10.1016/j.compag.2013.12.005

[2] Fontes L., Bontemps J.-D., Bugmann H., Van Oijen M., Gracia C., Kramer K., Lindner M., Rötzer T., & Skovsgaard J. P. (2010) Models for supporting forest management in a changing environment. *Forest Systems*, *19*, 8-29. https://doi.org/10.5424/fs/201019S-931

[3] Pretzsch H., Forrester D.I., & Rötzer T. (2015) Representation of species mixing in forest growth models. A review and perspective. Ecological Modelling, 313, pages 276-292. Doi: 10.1016/j.ecolmodel.2015.06.044

4 Shifley S.R., He H.S., Lischke H., Wang W.J., Jin W., Gustafson E.J., Thompson J.R., Thompson F.R.; Dijak W.D., Yang J. (2017) The past and future of modeling forest dynamics: from growth and yield curves to forest landscape models. Landscape Ecology. 32(7), 1307-1325. https://doi.org/10.1007/s10980-017-0540-9.

[5] Xi W., Coulson R.N., Birt A.G., Shang Z-B., Waldron J.D., Lafon C.W.; Cairns D.M., Tchakerian M.D., Klepzig K.D. (2009) Review of forest landscape models: types, methods, development and applications. Acta Ecologica Sinica, 29, 69-78.

2. Systematic methodology for participatory process

2.1. Context

The creation of a systematic methodology for participatory process in WP2 builds upon T2.1 (*Stakeholder consultation through participatory process*) and T2.2 (*Functional requirements*) under the leadership of project partner TUZVO. In this context, D2.1 has been released at the end of May 2022. The most important elements from this Deliverable are reported here below as summary of WP2 activities within the above-mentioned Tasks. Please refer to the full version D2.1 and its four Annexes and Database table for details about the work conducted in T2.1 and T2.2.

T2.1 aimed at developing a systematic procedure to engage with the stakeholders involved in the forest management - along different time horizons (from operational to tactical to strategic planning[6]) - in the context of combating wildfires. Conducted in parallel to T2.1, T2.2 aimed at finalizing the functional requirements of the SILVANUS platform based on the scenarios identified through engagement of T2.1 for the three phases A/B/C of forest management operations/services against wildfires. To pursue this objective, jointly with T2.1, T2.2 produced a '*Common Guideline for the Preparation and Comparative Analysis of Existing Sustainable Forest Management Services and Formalization of Functional requirements*" a document to standardize and harmonize the process of asking information to the stakeholders through Questionnaires, while also guiding SILVANUS partners on how to describe and provide information concerning existing measures, processes, technologies and services within the above described three phases (A/B/C) and how to improve them under explored and representative Operational Scenarios (OSs).

The collected information along T2.1 and T2.2 is going to be further exploited in T2.3 and T2.4, where it can be included in relevant Knowledge Base to be evaluated by experts in the field and to feed other WPs and Tasks for development purposes (datasets, models, Decision Support Systems) regarding the SILVANUS platform. Collected information will be also further used in comparative analyses and is going to be published in separate scientific publications (papers, monographs).

2.2. Guidelines for participatory process, questionnaire preparation, and evaluation

The two mentioned Tasks produced a Guideline document (Annex 2 of D2.1) concerning three aspects: 1) Participatory process, mainly managed by Pilot/OS leaders and stakeholders; 2) Questionnaire Tables' preparation, mainly managed by WP leaders and main WP2 participants; 3) Participatory process evaluation, again mainly managed by WP leaders and main WP2 participants.

Concerning the *Participatory process*, and for the successful joint execution of T2.1 and T2.2, it was deemed first important not only ensuring multi-disciplinarity by identifying a wide range of relevant stakeholders (e.g., representative/responsible for forest management, from firefighting operations to landscape restoration; external biodiversity/ecology/agriculture experts; regional councils; technology providers; citizens, etc.), but also selecting the most suitable method(s) of reaching them and surveying their awareness, practices and expectations. Methods could be e.g., questionaries via face-to-face or phone interviews, for single people or (focus) groups, or via email/web forms. Also, the type of data collected, from *primary* (for specific purposes) to *secondary* (for different/additional purposes within the project), must be clarified, as well as a review is needed on general to user-specific information from any existing source (scientific or grey literature, market, government archives, various communication channels) complemented by direct feedback collection from active users' involvement.

The Guidelines for stakeholders' engagement procedure are provided along with D2.1 which also lists products, tools, technologies, and services useful in OSs within each Phase (A/B/C) for tackling the spread

[6] Jeakins et al. (2004) A framework for sustainable forest management. Vancouver, B.C. Internal Canfor document.

of wildfires. More precisely: Phase A (Prevention and Preparedness) requires specification of significant and vulnerable areas, improving monitoring and signaling of fire hazards, engaging and interconnecting forestry management representatives and the public; Phase B (Detection and Response) concentrates on wildfires early detection and monitoring, wildfire mapping and fire behavior modeling, data integration and analytics, decision support systems application; Phase C (Restoration and Adaptation) focuses on building Knowledge Base, developing forest and landscape management alternatives for specific regions, applying Decision Support System (DSS) tools for alternatives assessment, and finding the optimal management approach for a specific area.

Pilot site/OS responsible, WP leaders and/or Task leaders have identified in advance relevant and responsive stakeholders according to the specific nature of analyzed phase (A/B/C). At first, they have been introduced to the SILVANUS project, its objectives and expected results (e.g., exploiting promotional materials of the project) and arranging an appointment/timeline for survey(s). Then, the remote questionnaires filling and/or interviews were conducted according to time schedule and respecting the template of questions (Questionnaire Tables) introduced in the Guidelines, with translation provided in advance by Pilot site leaders/participants when needed, and using JotForm program (see Annex 3 of D2.1), selected as it enables: support of input tables with different fields and formattable paragraphs (allowing narrative text); returning to complete the semi-finished survey; exporting into data format, aggregation, and visualization of results.

The basic and preliminary information that needs to be carefully registered about the survey, before collecting more content-related answers, are listed in the mentioned Guidelines: e.g., date and time; place; interviewer(s) contact details - expected to be Pilots, OSs, WPs or Tasks' responsible; respondents' contact details; consent by respondents to be cited in project documents and/or audio-/video-recorded, according to the project's Ethics; any condition/inaccuracy worthy to be marked. The Guidelines also recommend taking care to avoid both gaps and overlaps among users, surveys Tables or survey methods adopted (e.g., between online questionnaire forms and direct interviews to go from more general to detailed/clarification steps).

Together with the methodology for establishing the participatory processes, another methodology was proposed in the produced Guidelines, i.e., the approach for *Questionnaire Tables preparation* among partners, in terms of how adding/removing/editing questions or Tables, clarifying terminology, and commenting by partners, WP leaders, or Task leaders to be sure, before starting the consultation, that each Table allows asking information fitting-for-purpose. Also, possible field/data types are described in the Guidelines, as well as the finalized consent from partners (at WP to Task leader level) that they reviewed the Tables and that the formulation of questions in individual Questionnaire Tables tackle all the inputs and/or requirements for respective WPs/Tasks to be addressed during the consultation phase. The Questionnaire Tables were organized first into topics (areas) concerning the current/existing Status (S), functional Requirements (R) and operational scenarios Description (D) and then into subtopics for easily organizing the Pilots' description when the Tables will be completed, to finally feed the Architecture Design and Component Specification (see Table 1 derived from merging Figures 3 and 4 of Deliverable D2.1).

Finally, the steps to follow for effective *evaluation of the participatory process* are preliminarily listed in the D2.1, e.g., determine answers completeness, accuracy and understanding; digitizing the collected information into tables/documents following the same model; elaborate quantitative information – e.g., make statistics – for data analysis and answers' mapping; and identify any need of going into further detail. Indeed, to facilitate the analysis and evaluation process, information to be gathered for Pilot sites were organized to fill a Database classified by country and Tables, the latter distinguishing among the topics Status (S), Requirements (R) or Description (D) of operational scenarios and related sub-topics.

Table Code	Questionnaire Table Name	Sections of Pilot Description
Current Status (S)		**1. Scope**
S1	Pilot Summary	1.1. Identification
		1.2. Document Overview
S1.1	Overall Pilot Schema with overview of Technological Components	1.3. System Overview
		2. Referenced Documents
		3. Current System Situation
S2	Key factors to be considered in the Operational Scenario	3.1. Background, objectives, and scope
S3	Operational scenarios problems to be considered	3.2. Policies, constraints, and challenges
S3.1	Generic Characteristics of Policy	
S4	Generic Summary of the Operational Scenario Area	3.3. Description of the current system or situation
S5	Use of UAVs (Drones) and UGVs (Robots)	
S6	Remote sensing technology, Sensors and IoT Tools and Instruments	
S7	Existing Fire Alerting/Fire Detection Systems	
S8	Communication Protocols and Data Interchange	
S9	Big Data Frameworks	
S10	Cloud usage	
S11	Social Media Usage	
S12	Decision Support Systems	
S13	Available Datasets	
S14	Operational Description (Phase A, B, C)	3.4. Modes of operations for the current system or situation
S15	Organizational Description, Schema	3.5. User classes and other involved personnel
S16	Generic Stakeholder Profile	
Functional Requirements (R)		**4. Justification for and nature of changes**
R1	Forest Landscape models	4.1. Justification of changes
R2	Climate sensitive forest management	
R3	Forest resilience models	
R4	Forest fire ignition models	
R5	Prevention methodologies	
R6	Citizen engagement and awareness programme	
R7	Tailored weather/climate models for forest fire threat/risk assessment	
R8	Training Requirements	
R9	In-Situ data analytics	4.2. Description of desired changes/Functional Requirements
R10	Social sensing and conceptual extraction	
R11	UGV monitoring of wildfire behaviour	
R12	UAVs deployment for remote sensing	
R13	Earth observation data analytics	
R14	Situational awareness of fire danger index	
R15	Real-time monitoring of fire behaviour for response coordination	
R16	Decision support systems for detecting and preventing forest fires and forest restoration	
R17	Sorted and justified priorities for R1-R16 *(generated automatically)*	4.3. Priorities among changes

Table Code	Questionnaire Table Name	Sections of Pilot Description
R18	Changes which are wished but not realized in the project *(generated automatically)*	4.4. Changes considered but not included
Operational Scenarios Description (D)		
D1	Operational Scenarios (Phase A/B/C)	**6. Operational Scenarios**
D2	Key Parameters of the (SILVANUS) Platform	

Table 1 Matching among (sub-)topics of Questionnaire Tables and expected sections for Pilot Description.

2.3. Participatory process outcomes

To fill information about Pilots, on their current status, the functional requirements for the platform and possible operational scenarios, the Questionnaire Tables were presented to 61 stakeholders (number at the time of D2.1 release) from the following 10 countries: Australia (1), Croatia (6), Czech Republic (1), France (6), Greece (8), Indonesia (6), Italy (3), Portugal (9), Romania (2), Slovakia (19). Overall, 44% of respondents were from research organizations/universities, the remaining belonging in a roughly balanced way to these categories: first responders, firefighters, firefighting associations, forest and/or land owners, forest governance associations, IoT supply chain industry, timber industry, energy and construction industry, IT business, infrastructure traffic and road network, local residents and communities affected by wildfire, civil society organizations, think-tanks/NGOS, IT/software and technology developers on wildfire prevention, policy makers, health sector, financial sector, general public, public administration, other types. The deadline for answering the questionnaires was set to 8 April 2022, to have time for data analysis and evaluation before D2.1 submission. Information about the Brazilian Pilot site, its operational scenarios and functional requirements will be later supplemented.

2.3.1. Pilots' overview

In the D2.1 a description of the Pilots is provided, including pilots' summaries, status characteristics, stakeholders involved, high-level operational scenarios, priorities of the pilots, functional requirements for the SILVANUS Platform. In Figure 1, the map of Pilot sites' locations is reported.

Pilots' description has fed the Questionnaires Tables and *vice versa*, function of the information already available from partners and those collected under the topic on current/existing Status (S) of Questionnaires Tables through 18 (sub-topics) Tables (S1 to S16 in Table 1), whose answers are reported in the file *Deliverable 2.1_Database based on Questionnaire Tables.xlsx* supplementary to D2.1 and, as they are mostly in a narrative form, they are here synthetized as aggregated macro-information.

Pilots are organized per countries, 8 in EU: Croatia, Czech Republic, France, Greece, Italy (with two sites), Portugal, Romania and Slovakia; and 3 not in EU: Brazil, Indonesia and Australia. Annex 1 of D2.1 reports the status of completion of Questionnaires from 10 Pilots (waiting for completion from Brazil). Nine Pilots sites will demonstrate Operational Scenarios for Phase A (France, Italy (2 sites), Romania, Greece, Croatia, Portugal, Slovakia, Brazil), nine for Phase B (France, Italy (2 sites), Romania, Greece, Croatia, Czech Republic, Slovakia, Australia), and six for Phase C (Italy (one site), Greece, Portugal, Slovakia, Brazil, Indonesia); each Phase will conduct at least one demonstration scenario in one of the non-EU countries.

In terms of existing technology and services across Pilots/countries, they are mapped in Figure 2. It is evident how both fixes (CCTV) and mobile (unmanned vehicles) alerting and detection systems, and related big data analytics, are currently the most common technologies (≥3 countries reporting).

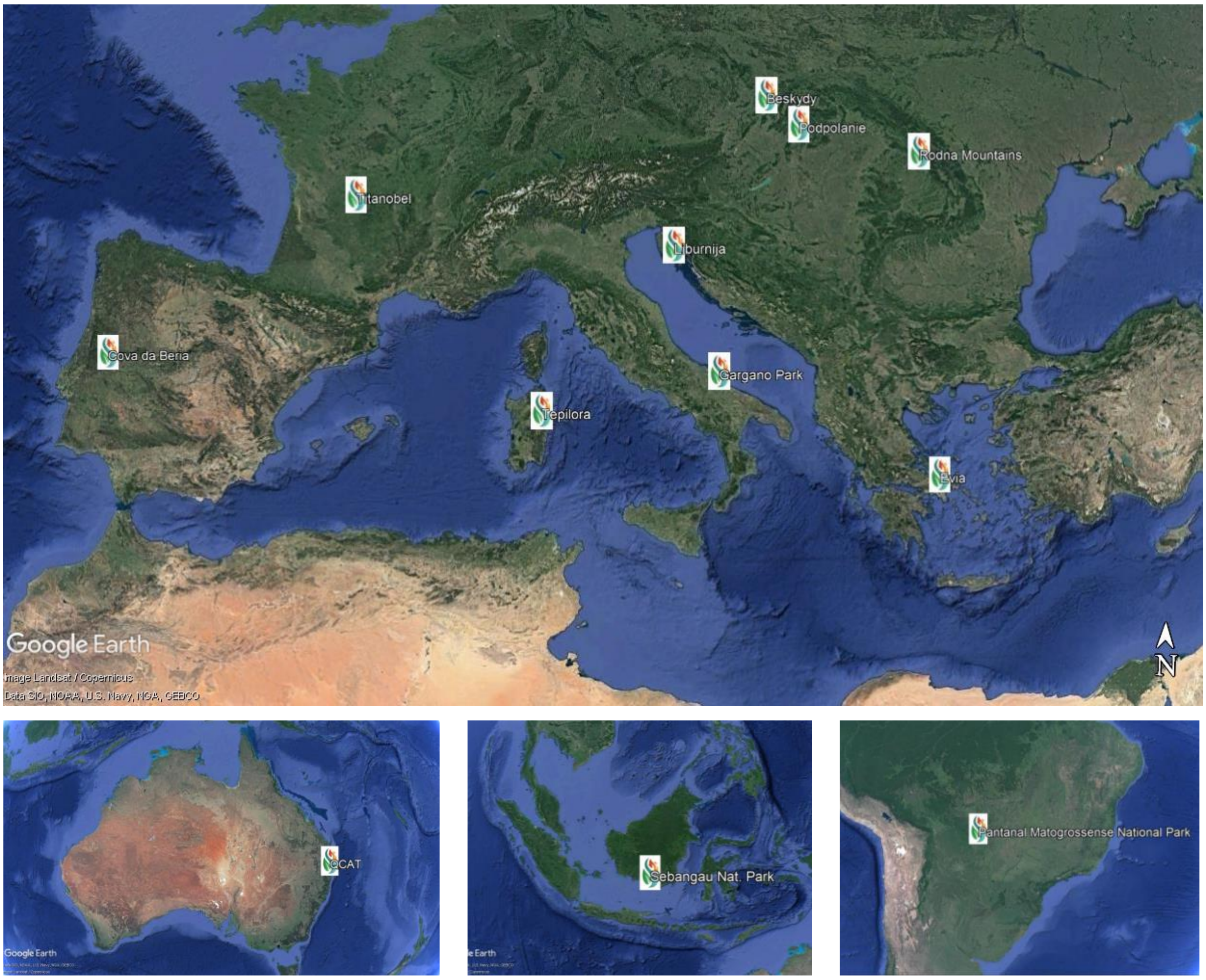

Figure 1 Location and identification name of SILVANUS Pilots (see D2.1): in EU (top) and in Australia, Indonesia, and Brazil (bottom, from left to right).

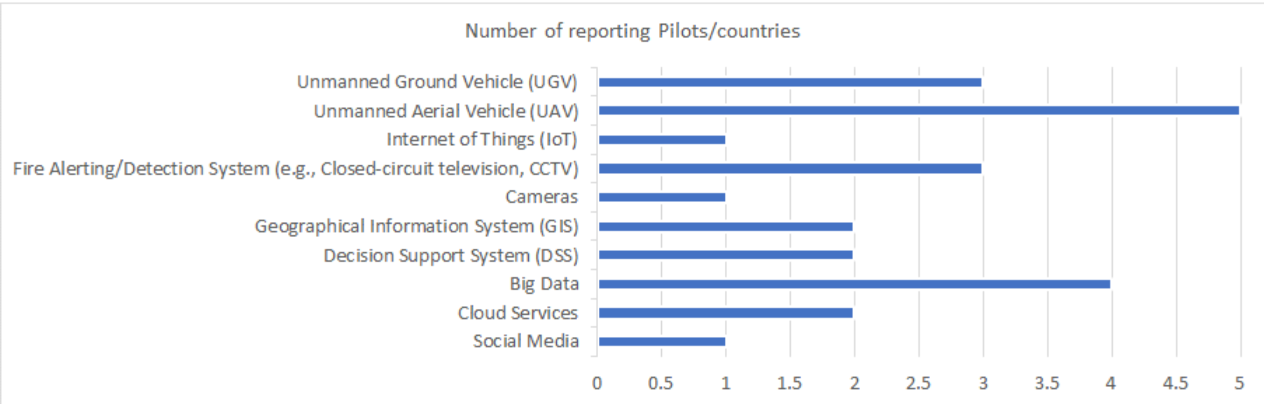

Figure 2 Number of Pilots/countries reporting the listed technology/service.

As for Use Cases, those more valued across Pilots/Countries (≥3, see e.g. Tables 10, 11, 12 of D2.1) are:

<u>Phase A (from a total of 20 intended Use Cases):</u>

- Mapping of the Pilot Site Area (roads, sites to be used as heliports) (FR, GR, HR, IT, SK)
- Public awareness campaign (GR, HR, IT)
- Fire hazard/ danger/susceptibility/vulnerability/risk map (GR, IT, HR, PT, RO, SK)
- Using Surveillance Cameras – preventive monitoring (HR, IT, SK)

Using tailored FIPAS mobile application to collect data about forest biodiversity. The data will be used for detection of forest fuel and for assessment of fire threat (GR, FR, IT, SK)

- IoT sensors (FR, GR, HR, RO, SK)

Phase B (from a total of 33 intended Use Cases):

- Using drones (drone swarm) to measure the ground temperature of the flames and fumes, the speed and direction of the wind with different sensors; equipped with gas sensors will make it possible to know the composition of the combustion gases and their dangers for the operators; monitoring the fire spread; inspection of human behavior for wildfire safety (CZ, FR, IT, RO, SK)
- Mapping of suitable water sources (GR, SK, RO)
- Decision Support System for Emergency Management (CZ, GR, HR)
- Fire propagation models (GR, HR, SK)
- Fast and reliable early warning through various sources, e.g., satellites, drones, CCTV (GR, HR, SK)
- UGV appliance will be used for ground monitoring and assessment. This appliance will be used for transport and firefighting purposes (CZ, HR, SK)
- Incident Management and Coordination supported with GINA mobile apps (CZ, HR, SK)

Phase C (from a total of 15 intended Use Cases)

- Sustainable forest management (forest silviculture, management, restoration) (IT, GR, SK)

2.3.2. Analysis and evaluation of collected data

Information on the Pilot status (S) were mentioned in Sect. 2.3.1, while that on Operational Scenarios Description (D) was collected through 2 (sub-topics) Tables (D1, D2 in Table 1), whose answers are reported in the file *Deliverable 2.1_Database based on Questionnaire Tables.xlsx* supplementary to D2.1 and, as they are largely made of descriptive and heterogeneous text, they are not easy to synthetize here. Therefore, we concentrate on summarizing results on Functional Requirements (R).

For each Functional Requirements' category in Table 1 (R1, R2, …, R16), several statements (sort of specific requirements) were presented to stakeholders, which had to express their view on the fact that requirements must (priority score=3), should (priority score=2), could (priority score=1) or wont (priority score=0) be meet through the SILVANUS platform, in each Phase A/B/C and considering cross-validation. Average priority scores within each Functional Requirements' (R) category are shown in Figure 3, while specific requirements are classified by their average priority across respondents and per Phase in Section 5 of D2.1. Table 2 highlights the top 3 R categories (ranked from the 1st to the 3rd position in dark to light green, respectively) for each Phase and for cross-validation. Both Figure 3 and Table 2 show how R13 on "Earth observation data analytics" is ranked among the most important across all Phases, followed by - function of the Phase considered - modelling approaches for fire ignitions and forest managements (including climate sensitive management and resilience) and by awareness raising, prevention and monitoring activities.

It is important to alert on the fact that results can be for now biased as not all the Pilots provided complete answers to Functional Requirements' section in the Questionnaire Tables (see status of Pilots' completion in Annex 1 of D2.1). Moreover, Functional Requirements' category R8 was collected as a narrative text and no quantitative prioritization score was given.

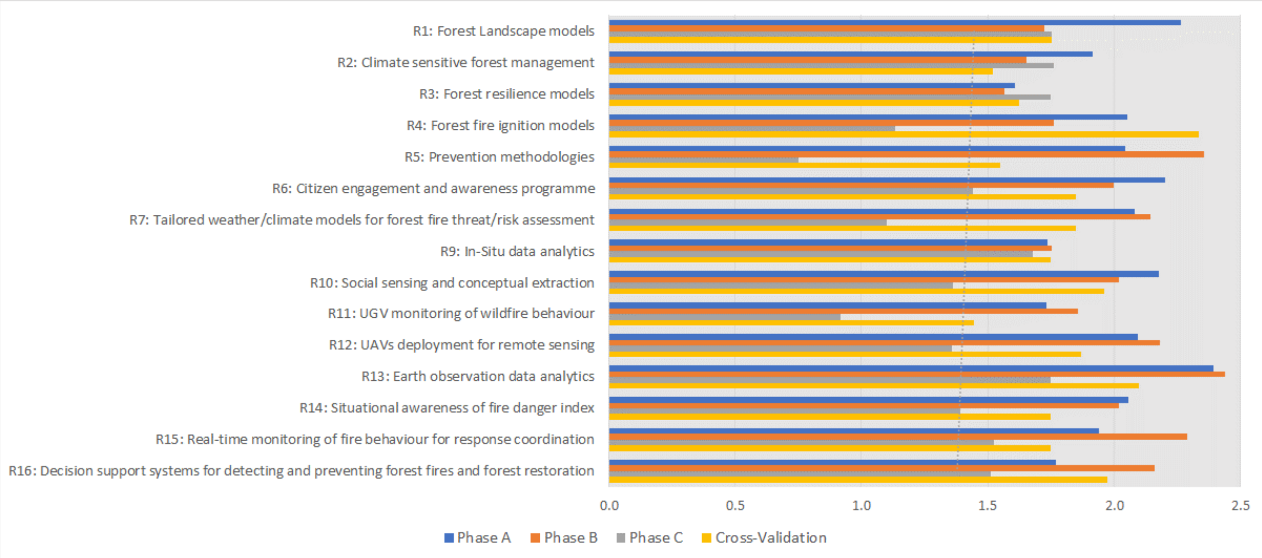

Figure 3 Priority for Functional Requirements' (R) categories.

Requirements	Phase A	Phase B	Phase C	Cross-Val
R1: Forest Landscape models	2.26	1.72	1.75	1.75
R2: Climate sensitive forest management	1.91	1.65	1.76	1.52
R3: Forest resilience models	1.61	1.57	1.75	1.63
R4: Forest fire ignition models	2.05	1.76	1.13	2.33
R5: Prevention methodologies	2.04	2.36	0.75	1.55
R6: Citizen engagement and awareness programme	2.20	2.00	1.44	1.85
R7: Tailored weather/climate models for forest fire threat/risk assessment	2.08	2.14	1.10	1.85
R9: In-Situ data analytics	1.74	1.75	1.68	1.75
R10: Social sensing and conceptual extraction	2.18	2.02	1.36	1.96
R11: UGV monitoring of wildfire behaviour	1.73	1.86	0.92	1.45
R12: UAVs deployment for remote sensing	2.10	2.18	1.36	1.87
R13: Earth observation data analytics	2.39	2.44	1.75	2.10
R14: Situational awareness of fire danger index	2.06	2.02	1.39	1.75
R15: Real-time monitoring of fire behaviour for response coordination	1.94	2.29	1.53	1.75
R16: Decision support systems for detecting and preventing forest fires and forest restoration	1.77	2.16	1.51	1.98

Table 2 Average priority score within each Functional Requirements' (R) category. Dark to light green tones indicate the first to third raking position (highest to lowest priority).

Table 3 shows instead the percentage of answers preferring the different priority levels for phase A, B and C. In case of no answer/priority provided, this could be due to technologies/solutions out of the scope of the Pilots or to information to be provided later during the project development.

At the end, the identified functional specific requirements were validated by interdisciplinary experts involved in the project consortium as well as by external stakeholders, covering three groups: foresters (2), firefighters and fire engineering experts (3) and civil protection experts (2), 7 persons in total. Results were graphically reported in Annex 4 and summarized in Section 6 of D2.1.

The consensus (results not shown but summarized from Table 8 of D2.1) was found at the level of 40%, 53%, 40% and 46% for Phase A, B, C and cross-validation values, respectively. This percentages become 50%, 31%, 31% and 58% in case of validation by foresters, 36%, 46%, 28% and 39% in case of validation by firefighters, and 40%, 33%, 24% and 36% in case of validation by civil protection experts. The number of people involved was constrained by the timeline of the activities, preventing from adopting any other multi-round approach (e.g., Delphi). Moreover, the reason for the overall low percentages of agreement is the high level of subjectivity which is given to the question asked and the heterogeneity among Pilot sites. Finally, it is noteworthy that most of not matching results between SILVANUS stakeholders and external experts differ for just one priority class.

		Must	Should	Could	Wont	No Answer
Requirements Phase A	R1: Forest Landscape models	35.2	15.9	13.6	1.1	34.1
	R2: Climate sensitive forest management	23.6	14.5	21.8	3.6	36.4
	R3: Forest resilience models	22.7	6.8	20.5	13.6	36.4
	R4: Forest fire ignition models	27.3	12.1	6.1	9.1	45.5
	R5: Prevention methodologies	25.0	13.6	9.1	6.8	45.5
	R6: Citizen engagement and awareness programme	27.3	15.5	7.3	4.5	45.5
	R7: Tailored weather/climate models for forest fire threat/risk assessment	22.7	13.6	18.2	0.0	45.5
	R9: In-Situ data analytics	14.5	21.8	18.2	5.5	40.0
	R10: Social sensing and conceptual extraction	36.7	10.0	15.0	5.0	33.3
	R11: UGV monitoring of wildfire behaviour	18.2	3.0	18.2	6.1	54.5
	R12: UAVs deployment for remote sensing	21.8	25.5	12.7	1.8	38.2
	R13: Earth observation data analytics	40.9	9.1	11.4	2.3	36.4
	R14: Situational awareness of fire danger index	19.7	22.7	16.7	0.0	40.9
	R15: Real-time monitoring of fire behaviour for response coordination	25.0	13.6	18.2	2.3	40.9
	R16: Decision support systems for detecting and preventing forest fires and forest restoration	17.0	19.3	11.4	9.1	43.2
Requirements Phase B	R1: Forest Landscape models	19.3	28.4	18.2	10.2	23.9
	R2: Climate sensitive forest management	14.5	29.1	18.2	10.9	27.3
	R3: Forest resilience models	15.9	22.7	20.5	13.6	27.3
	R4: Forest fire ignition models	24.2	18.2	3.0	18.2	36.4
	R5: Prevention methodologies	34.1	20.5	6.8	2.3	36.4
	R6: Citizen engagement and awareness programme	22.7	24.5	10.0	6.4	36.4
	R7: Tailored weather/climate models for forest fire threat/risk assessment	27.3	18.2	18.2	0.0	36.4
	R9: In-Situ data analytics	16.4	27.3	20.0	5.5	30.9
	R10: Social sensing and conceptual extraction	28.3	26.7	13.3	6.7	25.0
	R11: UGV monitoring of wildfire behaviour	24.2	15.2	15.2	9.1	36.4
	R12: UAVs deployment for remote sensing	29.1	27.3	12.7	1.8	29.1
	R13: Earth observation data analytics	45.5	15.9	9.1	2.3	27.3
	R14: Situational awareness of fire danger index	25.8	19.7	21.2	1.5	31.8
	R15: Real-time monitoring of fire behaviour for response coordination	31.8	18.2	18.2	0.0	31.8
	R16: Decision support systems for detecting and preventing forest fires and forest restoration	33.0	14.8	14.8	3.4	34.1
Requirements Phase C	R1: Forest Landscape models	17.0	11.4	13.6	6.8	51.1
	R2: Climate sensitive forest management	10.9	18.2	10.9	5.5	54.5
	R3: Forest resilience models	18.2	6.8	11.4	9.1	54.5
	R4: Forest fire ignition models	15.2	3.0	0.0	27.3	54.5
	R5: Prevention methodologies	4.5	6.8	6.8	27.3	54.5
	R6: Citizen engagement and awareness programme	10.0	11.8	11.8	11.8	54.5
	R7: Tailored weather/climate models for forest fire threat/risk assessment	0.0	13.6	22.7	9.1	54.5
	R9: In-Situ data analytics	12.7	12.7	12.7	7.3	54.5
	R10: Social sensing and conceptual extraction	16.7	3.3	11.7	18.3	50.0
	R11: UGV monitoring of wildfire behaviour	3.0	3.0	18.2	12.1	63.6
	R12: UAVs deployment for remote sensing	7.3	12.7	14.5	10.9	54.5
	R13: Earth observation data analytics	18.2	11.4	2.3	13.6	54.5
	R14: Situational awareness of fire danger index	4.5	19.7	3.0	13.6	59.1
	R15: Real-time monitoring of fire behaviour for response coordination	9.1	11.4	15.9	4.5	59.1
	R16: Decision support systems for detecting and preventing forest fires and forest restoration	9.1	12.5	13.6	6.8	58.0

Table 3 For each phase, percentages of answers supporting the priority levels, including no answer/priority given.

In terms of functional requirements' category, their aggregated agreement was (in **bold** when > 50%): 44% (R1), 30% (R2), 44% (R3), 17% (R4), 50% (R5), **57.5% (R6)**, 12.5% (R7), 45% (R9), **55% (R10)**, 50% (R11), **60% (R12)**, **56% (R13)**, 33% (R14), 37.5% (R15), 44% (R16). Interestingly, among the highest agreements, there is the one on R13 that is also at the top of priority categories.

2.4. Concluding remarks and next steps

The first six months of the project T2.1 and T2.2 were dedicated to establishing and harmonizing procedures for Questionnaire Tables' preparation, presentation to stakeholders and evaluation, and to collecting information and requirements in terms of possible data, models, and tools expected to be available from the SILVANUS platform. Although the activities of the two Tasks are officially concluded, continuous feedbacks and new inputs (e.g., Brazil Pilot site description or further additions on the Questionnaire

Tables) will be however considered and included in the Database whose answers to the Questionnaire Tables have been collected and preliminary analyzed in D2.1 and further synthetizes also in the present Deliverable. Among requirements, “Earth observation data analytics” resulted among the most important across all Phases, followed by modelling approaches for fire ignitions and forest managements (including climate sensitive management and resilience) and by awareness raising, prevention and monitoring activities, these more or less important in function of the Phase considered.

3. Review of forest landscape models for the pilot demonstrations sites

3.1. Context

The models, often embedded into more comprehensive Decision Support Systems (DSSs), are increasingly used as instruments for operational (short term) to strategic (long term) planning in the forestry sector. SILVANUS will capitalize on and leverage models/DSSs for the different phases A/B/C to be covered, to simulate processes and dynamics ranging from fire danger to fire spread to forest resilience against fires, considering forest structure and composition, also reflecting alternative climate scenarios and management options. T2.3 aims at reviewing, studying, and selecting the forest landscape models/DSSs to be adopted in Pilot sites, through three main subtasks that will cover different but interconnected aspects:

- Identifying and describing models that incorporate multiple spatiotemporal processes such as both natural biotic (e.g., pests, diseases) and abiotic (e.g., wildfires, climate thermal and humidity extremes) disturbances, as well as human management and interventions (e.g., planting, harvesting, thinning, fire suppression). This assessment and categorization work will lead to decisions on models and/or DSSs, and related specifications, to be exploited in SILVANUS, and to a refined definition of the scope of demonstration activities in Pilots. Successively, the steps to arrange selected forest models/DSSs as practical tools for studying forest management, ecological assessment, restoration planning, and climate change impacts in Pilots will be conducted, aiming to be progressively ready since January 2023.
- As the importance of structurally diverse forests for the conservation of biodiversity, post fire suppression and provision of a wide range of ecosystem services has been widely recognized, the study of diversification strategies for forests will be supported by the analysis of several diversity parameters, variables and metrics related for example to the measurement of tree species richness (including the regeneration layer), statistics of diameter at breast height (DBH) and stand heights, diversity of bark, flowering, fructification and decay classes, diameter of downed and standing deadwood.
- To optimize the forest landscape management according to the wildfire threat, also management systems and strategies of forest fuel (especially of fine fuel whose moisture content is key to calculate the fire danger index) will be studied and reviewed. Function of forest types (based on location, species composition, existing management operations) fuel management alternatives focusing on wildfire prevention and mitigation will be identified and further evaluated by the stakeholders in selected countries, exploiting the participatory processes in T2.1. T2.3 is expected to lead to a workshop in March 2023 on fuel management strategies.

The first subtask is, in particular, described in the present Deliverable, also because through this sub-component T2.3 is strongly connected to T2.4, where a special category of forest models (see Sect. 4) will be reviewed, classified, and chosen to be implemented in selected Pilots.

3.2. General Forest models' categorization

As the term "forest models" can have a very general and multi-faceted meaning, the first activity conducted in T2.3 was a screening of the terminology about forest models potentially useful to be adopted for SILVANUS purposes, especially in the context of the Description of Action (DoA). A set of 13 forest model categories (Table 4) was identified and agreed among partners, being aware that a clear dividing line among such definitions is not straightforward and some can intersect or slightly overlap. Moreover, it is important to note that the term "model" not only refer to numerical or, in general, quantitative procedures (with mathematical formulation to reproduce physical, statistical, empirical, or more complex relationships), but also to management, organizational, governance and assessment approaches. As planned and anticipated, three of the below categories (2,4 ,6 in Table 4) will be better addressed in T2.4.

Forest Model Category	Description
1. Climate resistant models	Models aimed at resilience to climate change, for example, selection of forest species resistant to climate change.
2. Climate sensitive forest models	These models consider climate change either as an input parameter and/or in the desired result.
3. Environmentally sustainable models	Models that consider the environmental impact of various activities.
4. Forest ecosystem models	Models that describe forests, usually examining certain functions at a time.
5. Forest fire ignition models	Models that assess the possibility of starting a fire based on environmental - climatic and anthropogenic factors.
6. Forest growth model	Forest growth models, mainly wood stock growth models (tree or forest volume). There are also models of cluster structure, i.e., regarding composition of different sizes and ages in each forest location. These models are suitable for predicting the amount of fuel.
7. Forest landscape models	These are models that describe the forest and / or functions-or parameters, etc., to a large extent based on the spatial change of the factors that affect the forest (soil, climate, relief, etc.).
8. Forest models	It is a general term that refers to models related to forests and, mainly, forest management. They may not be mathematical models but general methods of forest management, such as managing to produce multiple goods from a forest. Also, included in the term, are sub-models that relate to forest parameters such as the increase of forests both in volume and in age (height) composition of trees in each stand.
9. Forest Resilient models	Models regarding functions that are or should be made resilient or durable in terms of various parameters (in our case, it mainly concerns the climate).
10. Forest restoration activities modeling	Modeling of forest restoration processes from disasters.
11. Fuel models	These models describe forest biomass when this is considered as a combustible material. They have the form either of a series of numbers that represent the parameters of fuel load (usually ground fuels) or equations (usually allometric) from which the parameters of the canopy fuel (biomass) of trees can be estimated.
12. Governance models	Governance models for dealing with specific problems (policies and implementation measures).
13. Risk assessment models	Models for risk assessment models (with respect to fire or another hazard).

Table 4 Types of forest models mentioned in SILVANUS proposal.

3.3. From models to Decision Support Systems (DSSs): the inventory

Successively to the initial clarification on forest models' definition, and to better respond to SILVANUS purposes, the focus was enlarged from models to Decision Support Systems (DSSs). The former is indeed often a core component of the latter, which in addition comprises elements to concretely support decisions (e.g., a practical tool with software implementation; functionalities for combination, synthesis and/or visualization of outputs for better interpretation; link to catalogue of options and their possible outcomes/effects).

In order to guide the inventory of existing landscape of forest models/DSSs, a number of descriptive fields were prepared in a Table to list models/DSSs, assessing their value, possible contribution and feasibility for implementation in SILVANUS, in order to address one or more from the following domains: firefighting, forestry, forest resilience, and fire impacts mitigation. Models/DSSs are also characterized according to:

- Their scope and in which phase(s) (A/B/C) they could be useful: e.g., firefighting; training; fire simulator; fire risk assessment, resilience, or mitigation; fuel management; fire event management, like protection of population.
- Nature of model: mathematical; non-mathematical (e.g., processes, knowledge, decision methodology); and/or based on one or more indices.

In total 8 macro categories of models/DSSs based on scope and nature were identified (first digit X of the model/DSS identification code MXX), and 22 inventory categories have been further defined based on specific knowledge field, e.g., calculation of wildfires characteristics, stand evolution, biomass (fuel) estimation, climate change prediction. The reviews within each category are ongoing and performed by leading and contributing partners as identified during T2.3/T2.4 meetings and exchanges. This template is also valid for existing tools (coded as TXX) implementing respective models.

By analyzing Table A1, overall, all inventory categories include mathematical approaches, while half of them cover also non-mathematical methodologies, and 86% (19) typically involve index- or indices-based models. Phase A, Phase B and Phase C can be supported by 95% (21; mostly for training and forest resilience), 55% (12; mostly for firefighting and citizen protection) and 68% (15; mostly fire impact mitigation) of model/DSS categories.

Building on such summary Tables, efforts are now devoted to:

1. Research and identification of suitable models and tools per category;
2. Assessment of models and tools, including supporting evidence in terms of their performances and with reference to their suitability in SILVANUS due to the sites' characteristics;
3. High-level description of models and tools;
4. Detailed description of most promising models and tools, e.g., with input/output variables.

This work is supported by a Knowledge Base compiled in a dedicated folder on the project's MS Teams repository (see e.g. *Appendix A1 and Appendix A2*) and, in particular, by two template tables (file *Model Inventory-Evaluation 2.xlsx*) that, first for each model, identify a unique code (e.g., MXX.Y where MXX is the inventory category Appendix A1) and allow populating information in the two following sections made, respectively, of dedicated descriptive and evaluation elements (the latter to support comparison purposes):

- Model Metadata
  - Model Name or Title - *Specify the name or title of the model, as most commonly used in the existing literature*
  - Nature of Model - *Specify: Mathematical, Non-mathematical (e.g., Knowledge, Processes), Index/Indices, Other*
  - Applicability in Phases - *Specify: A, B, C or combinations*
  - Main Capabilities of the Model - *Specify keywords (free selection) with main capabilities or features of the model*
  - Main Restrictions of the Model - *Comments on main limitations of the model, e.g., regarding the accuracy of measurements, the prediction of the values of variables, etc.*
  - Implemented in S/W Products or Tools - *Specify any existing S/W products or tools where this model is implemented*
  - Additional Comments - *Include any additional comments, if necessary*
  - Main Reference(s) - *Specify the main references (literature or other sources) that describe or review this model - Store these papers into the Knowledge Base, in a dedicated folder, i.e., MXX.Y folder*
- Model Assessment (with scores in specific criteria)

- Suitability and Completeness - *Degree to which the model provides functions that meet user needs (when used under specified conditions), as well as degree to which the set of functions covers all user objectives in specific operational scenarios. Include a single integer score from 0 to 10. Convention:*
  Excellent (8-10)
  Satisfactory (6-8)
  Moderate (4-6)
  Inadequate (2-4)
  Unacceptable (0-2)
  Then, specify the weight (importance) for Suitability and Completeness as criterion for the assessment
- Prediction Capacity - *Specify the prediction capacity (e.g., relevance, accuracy, or other suitable metric) as a percentage from 0 to 100% (the higher the better). Estimate an average value from the evidence that exists in literature reviews and papers*
  Then, specify the weight (importance) for Prediction Capacity as criterion for the assessment
- Data Requirements - *Perform an assessment of the data requirements of the model. Higher data requirements (more data or more parameters) should yield lower scores. Convention - Data requirements are:*
  Few and very realistic (8-10)
  Moderate but generally realistic (6-8)
  Many but could be achieved under certain conditions (4-6)
  Very high (2-4)
  Extremely high (unrealistic) (0-2)
  Then, specify the weight (importance) for Data Requirements as criterion for the assessment
- Easy to implement as S/W - *Assess how easy it will be to implement the model as a S/W tool or component within the SILVANUS Platform.*
  Easy and straightforward (8-10)
  Achievable but with some difficulties (6-8)
  Hard but could be achieved with sufficient resources (4-6)
  Very hard (2-4)
  Extremely hard (unrealistic) (0-2)
  Then, specify the weight (importance) for "Easy to implement as S/W" as criterion for the assessment
- Model-specific Criterion A (optional) - *Specify another relevant criterion (if necessary) for this type of models, or leave blank*
  Then, specify the weight (importance) for "Model-specific Criterion A" as criterion for the assessment
- Model-specific Criterion B (optional) - *Specify another relevant criterion (if necessary) for this type of models, or leave blank*
  Then, specify the weight (importance) for "Model-specific Criterion B" as criterion for the assessment

An example of model metadata for M22 category in Table A1 (Canopy fuel) is provided in Figure 4.

	Model Metadata							
Model Code	Model Name or Title	Nature of Model	Applicability in Phases	Main Capabilities of the Mo	Main Restrictions of the Mo	Implemented in S/W Products or Tools	Additional Comments	Main Reference(s)
M22.1	Alexander and Cruz (2010)	Mathematical	A	Given three user inputs (i.e. stand area basal area, average stand height and stand density), canopy base height (CBH), canopy fuel load (CFL), and canopy bulk density (CBD) are automatically calculated for one of the four fuel types namely ponderosa pine, lodgepole pine, Douglas-fir and mixed conifer fuel types.		Canopy Fuel Stratum Characteristics Calculator is a software application that intergrates the regression equations developed by M.G. Cruz, M.E. Alexander and R.H. Wakimoto (2003. International Journal of Wildland Fire 12, 39-50). They have been programmed into an excel spreadsheet	A copy of the Canopy Fuel Stratum Characteristics Calculator software is readily available for downloading from the FRAMES website (http://frames.nbii.gov/cfis).	Alexander M.E. & Cruz M.G. (2010) Introducing the Canopy Fuel Stratum Characteristics Calculator. Proceedings of 3rd Fire Behavior and Fuels Conference, October 25-29, 2010, Spokane, Washington, USA Published by the International Association of Wildland Fire, Birmingham, Alabama, USA. https://www.frames.gov/documents/catalog/alexander_and_cruz_2010_poster.pdf

Figure 4 Example of metadata compiled for a model on Canopy Fuel.

Similarly, for existing tools, a unique code TXX.Y identifies the tool corresponding to inventory category MXX, and the following sections and elements should be provided:

- <u>Tool Metadata</u>
  - Tool Name or Title - *Specify the name or title of the tool, as most commonly used in the existing literature*
  - Installability - *Specify the type of S/W and the H/W or S/W requirements for its successful installation*

- Applicability in Phases - *Specify: A, B, C or combinations*
- Main Capabilities of the Tool - *Specify keywords (free selection) with main capabilities or features of the tool*
- *Main Restrictions of the Tool - Comments on main limitations of the tool*
- List of Integrated Models - *Specify the model(s) that the tool implements and integrates*
- Additional Comments - *Include any additional comments, if necessary*
- Main Reference(s) - *Specify the main references (literature or other sources) that describe or review this tool - Store these resources into the Knowledge Base, in a dedicated folder, i.e., TXX.Y folder*

• Tool Assessment

- Functional Suitability and Completeness - *Degree to which the S/W product or tool provides functions that meet user needs (when used under specified conditions), as well as degree to which the set of functions covers all user objectives in specific operational scenarios. Include a single integer score from 0 to 10. Convention:*
  Excellent (8-10)
  Satisfactory (6-8)
  Moderate (4-6)
  Inadequate (2-4)
  Unacceptable (0-2)
  Then, specify the weight (importance) for Functional Suitability and Completeness as criterion for the assessment
- Functional Correctness - *To what extent the outcomes of the S/W product or tool can be considered as correct and precise? Estimate an average value from the evidence that exists in literature resources. Convention:*
  Excellent (8-10)
  Satisfactory (6-8)
  Moderate (4-6)
  Inadequate (2-4)
  Unacceptable (0-2)
  Then, specify the weight (importance) for Functional Correctness as criterion for the assessment
- Compatibility and Interoperability - *Degree to which the S/W product or tool can exchange information with other products, systems, or components, and/or perform its required functions while sharing the same H/W or S/W environment. Degree to which a tool can perform its required functions efficiently, exchange information and use the information while sharing a common environment and resources with other products, without detrimental impact on any other product. Specify a single integer score from 0 to 10. Convention:*
  Excellent (8-10)
  Satisfactory (6-8)
  Moderate (4-6)
  Inadequate (2-4)
  Unacceptable (0-2)
  Then, specify the weight (importance) for Compatibility and Interoperability as criterion for the assessment
- License Type and IPR - *Assess how open or restrictive the IPR or license type of the tool are. Convention:*
  Open (any restrictions are insignificant) (8-10)
  Few restrictions (6-8)
  Important restrictions (4-6)
  Very important restrictions (2-4)
  Closed or proprietary, with several and severe limitations (0-2)
  Then, specify the weight (importance) for "License Type and IPR" as criterion for the assessment
- Tool-specific Criterion A (optional) - *Specify another relevant criterion (if necessary) for this type of models or leave blank.*
  Then, specify the weight (importance) for "Tool-specific Criterion A" as criterion for the assessment
- Tool-specific Criterion B (optional) - *Specify another relevant criterion (if necessary) for this type of models or leave blank.*
  Then, specify the weight (importance) for "Tool-specific Criterion B" as criterion for the assessment

From the above, it becomes apparent that a tool might implement or integrate one or several models, whereas a model can be implemented in none, one or several tools (many-to-many relationship). An example of tool metadata for T23 (connected to M23 category in Table A1, Fire risk assessment) is provided in Figure 5.

Tool Code	Tool Metadata							
	Tool Name or Title	Installability	Applicability in Phases	Main Capabilities of the Tool	Main Restrictions of the Tool	List of Integrated Models	Additional Comments	Main Reference(s)
T23.1	Fire Risk Analysis	Python code	A	Download satellite images (MODIS) Deep learning model training	Need customization for additional features	Xception Logistic Regression Desision tree classifiers Random Forest		https://github.com/czaloumi/fire-risk-analysis

Figure 5 Example of metadata compiled for a tool on Fire Risk Analysis.

3.4. Concluding remarks and next steps

The review of models and related tools is ongoing, and has been planned as incremental, i.e., progress status will be checked according to periodical updates/discussion around every two months, to avoid creating bottlenecks while helping instead to streamline the overall platform development, with a first consolidated version of the inventory partly feeding the Minimum Viable Product (MVP) of March 2023. Then, T2.3 will continue adding models and tools whose description will make part of D2.4 (to be released in project's Month24) and will provide the content of a review paper.

Besides complementarity with T2.4, one of the main priorities in the following period is the alignment between forest modeling (in WP2 but also in WP6 and WP7 for restoration and resilience, respectively) and technical activities (WP4/WP5/WP8), the former feeding into the latter for implementation.

4. Climate sensitive forest models

4.1. Context

Nowadays the forestry sector is marked by global climatic and socio-economic changes. Climate change, reflected by modified average conditions, increased weather variability and more frequent occurrence of extreme events alters forest production, structure, and health[7]. Socio-economic changes affect the use of forests towards the expansion of ecosystem services. Forest management - ranging from the removal of certain individuals (thinning) or part of individuals (pruning) to the alteration of nutrients availability (fertilization)[8] - is the essential tool for ensuring the provision of all ecosystem services, from timber production to intangible services such as recreation and soil protection[9]. To orient the decision-making, forest managers rely on scientific tools that could span from simple growth models to sophisticated simulators[10].

While Yield Tables have been frequently used for forest management planning purposes, they are not currently able to respond properly to the expectations of planners for the following reasons: *i)* they are only valid under the conditions in which they were developed; *ii)* they are intended for mono-species stands with a limited range of management options; and *iii)* they are not able to respond to climate change and extreme events effects. Therefore, the updating of planning tools and procedures is necessary in the context of global change. Forest models, running in computing machines to reproduce the behaviour of forest ecosystems, can be particularly useful as they are the abstraction of real forest stand dynamics into a conceptual or biometric description. The degree of abstraction depends on existing knowledge about the structure and behaviour of the real forest ecosystems well as on the role implied by the model.

Within WP2 of SILVANUS, T2.3 (see Sect. 3) is dedicated to a review of a wide range forest landscape models, tools and derived DSSs, while T2.4 is further focusing on three model definitions given in Table 4 (i.e., the n. 2., 4., 6.), in particular those referring to models allowing to simulate the growth dynamics of forest ecosystems taking into account managements but also climate drivers. In practice, T2.4 will review models for inventory categories in Table A1 flagged as M41 (DSS for firefighting: *Models for climate change impact on forests: especially those of forest management adaptation to climate change impact on forests*) and M43 (DSS for forest resilience and fire impact mitigation: *Models to estimate the effect of environmental factors on forest susceptibility to fire, esp. climate*). For the sake of simplicity, we will refer to all these model hereafter as “climate sensitive forest models”. The work in T2.4 started with a classification of models according to several criteria described in the next Section, with the aim of contributing to the inventory in T2.3 thanks to a first screening of suitable approaches among climate sensitive forest models, and then choosing the model(s)/tool(s) more promising to be implemented though the SILVANUS platform and applied in selected Pilot sites. To this aim, also a quick scan of datasets to rely on as possible sources of input data and parameters was undertaken and are here reported.

4.2. Definition and classification of climate sensitive forest models

Many forest growth models have been developed with a considerable variability in their structure, the processes that are represented as well as their temporal and spatial resolutions and scales. The review of

[7] Seidl R., Thom D., Kautz M., Martín-Benito D., Peltoniemi M., Vacchiano G., Wild J., Ascoli D., Petr M., Honkaniemi J., Lexer M., Trotsiuk V., Mairota P., Svoboda M., Fabrika M., Nagel T., & Reyer C. (2017) Forest disturbances under climate change. *Nature Climate Change*, *7*, 395-402. https://doi.org/10.1038/nclimate3303

[8] Twery M.J. & Weiskittel A.R. (2013) Forest-Management Modelling. In Environmental Modelling (pp. 379–398). John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118351475.ch23

[9] Fabrika M., Valent P. & Merganičová K. (2019) Forest modelling and visualisation – state of the art and perspectives. Central European Forestry Journal, 65(3–4), 147–165. https://doi.org/10.2478/forj-2019-0018

[10] Antón-Fernández C. & Astrup R. (2022) SiTree: A framework to implement single-tree simulators. SoftwareX, 18, 100925. https://doi.org/10.1016/j.softx.2021.100925

climate sensitive forest models is based on some criteria, strongly interconnected. Models can be distinguished into:

- *Individual-tree, size class to whole-stand level models.* Such models have each its advantages and limitations. For example, whole-stand and size class models are the most appropriate for evenly aged stands of a single species and are not the most adapted approaches especially when multiple thinning must be represented[11]. In contrast, individual-tree models provide the highest resolution of prediction and are also effective for representing even-aged, single-species, mixed-species and multi-cohort stands, as well as the effects of management, particularly of complex thinning regimes. However, while individual-tree models can be useful for examining patterns resulting from tree-level interactions, those models typically require more calculations, and therefore, can propagate errors when going to the stand level[12]. This is exacerbated when processes that significantly influence tree-level (e.g., mortality), are ignored or inadequately represented like e.g., microsite heterogeneity[13]. A potential problem for stand-level models is instead due to processes that significantly influence stand-level growth but are difficult to model at the stand level. While many tree interactions depend on tree sizes or spatial location of trees, it is not clear which of these have effects that cannot be summarized at the stand level. However, until now, individual-tree models have not yet been shown to be more accurate at the stand level for forests. For individual-tree models to be more accurate, the improvements in accuracy resulting from the higher resolution would need to be greater than the error associated with the additional calculations at the tree level that are required to account for all factors that significantly influence individual tree growth and mortality, or there would need to be a tree-level process that strongly influences stand growth but cannot be modelled accurately at the stand level[14].
- *Single to mixed species models, the latter representing competition among species.* Four main approaches are usually applied to predict stand growth of mixtures: a) averaging pure stands characteristics, i.e., where no information is available regarding mixed-forest growth, this latter is simply assumed to be the weighted mean of monocultures' productivity; b) integration of mixed effects using multipliers, i.e., where mixing effects are directly integrated using multipliers that represent the deviation of specific species response in mixed stands compared to pure stands; c) including competition indices in the model to predict stand growth making it possible to regulate the individual-tree's growth and the probability of survival in the subsequent period; d) using a physiological process-based approach, to directly consider the current partitioning of resources between species. Recent works on yield distribution have shown that species interactions in mixtures generate emergent properties and modify the stand environment. According to many recent studies, the productivity of mixed stands can exceed the weighted mean productivity by 50% in mixtures with nitrogen-fixing species[15]. This indicates that relying on the weighted mean of monocultures will not enable the simulation of these mixed species dynamics and that closer consideration of mixing effects will be necessary in future models[14].
- *Empirical, process-based to hybrid approaches*. Empirical models are limited to the conditions represented in the data sets from which they were developed and may be less reliable when extrapolated

[11] Twery M.J. & Weiskittel A.R. (2013) Forest-Management Modelling. In Environmental Modelling (pp. 379–398). John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118351475.ch23
[12] Grimm V. (1999) Ten years of individual-based modelling in ecology: What have we learned and what could we learn in the future? Ecological Modelling, 115(2), 129-148. https://doi.org/10.1016/S0304-3800(98)00188-4
[13] García O. (2017) Cohort aggregation modelling for complex forest stands: Spruce–aspen mixtures in British Columbia. Ecological Modelling, 343, 109–122. https://doi.org/10.1016/j.ecolmodel.2016.10.020
[14] Forrester D.I., Hobi M.L., Mathys A.S., Stadelmann G. & Trotsiuk, V. (2021) Calibration of the process-based model 3-PG for major central European tree species. European Journal of Forest Research, 140(4), 847–868. https://doi.org/10.1007/s10342-021-01370-3
[15] Forrester D.I. & Tang X. (2016) Analysing the spatial and temporal dynamics of species interactions in mixed-species forests and the effects of stand density using the 3-PG model. Ecological Modelling, 319, 233–254. https://doi.org/10.1016/j.ecolmodel.2015.07.010

to new climates, site conditions, species combinations, and silviculture[16,17]. In contrast, models based on general, fundamental ecophysiological processes (process-based models, PMB) can potentially provide robust extrapolations to novel conditions[18]. It is worth mentioning that the current trend in forest modeling is to combine the two different classes (hybridization). Hybrid models incorporate the robustness of empirical models while allowing extrapolation to new site conditions. They also have the ability to provide output of interest to forest managers and represent the effects of forest management. The unavailability of physiological parameter values for several tree species makes using mechanistic to hybrid models challenging. However, the combination of literature review, direct estimation of many allometric parameters and calibration methods make it possible to estimate parameters of process-based models. As example, Bayesian optimization has been demonstrated several times to provide promising results[14,19], and when properly calibrated, mechanistic models were just as effective or better than empirical models[20]. To provide relevant predictions, machine learning models can be also adopted. They require a big amount of data, an appropriate choice of the algorithm and a clear definition of inputs and outputs, while PBMs rely on the knowledge about causal mechanisms that are generated through experiment without the need for big datasets. PBM can be used as a predictive tool where experiments are difficult or costly to perform while machine learning models, similarly to empirical approaches, can only make predictions in the space where they were developed[21], although requiring less computational resources. For the aim of T2.4, the definition in Kurt (1994)[22] will be considered.

Moreover, whichever the model is, the data required for model application can be roughly distinguished into three main types. System parameters are ecophysiological constants derived from e.g., empirical measurements and literature or sometimes fitted in a way to minimize the cost function. The values of those parameters remain the same and do not change from one simulation to another. The current status of the system is instead described by the means of state variables, whose values change at the end of each simulation; this category of variables is considered as an *input* at the time of the model initialization and an *output* since the performance of the first simulation. The evolution of the system status is finally influenced by both endogenous and exogenous variables while only endogenous variables are influenced by the state variables. The environment (e.g., the climate) controls the system with exogenous variables, while it regulates it with endogenous variables. In addition, given the fact that growth models are developed for forest planning purposes, management (silvicultural interventions) can be also included as exogenous inputs to the model. Function of the type of models, exogenous variables are provided usually according to a specific and regular temporal step (e.g., hourly to annual time series) and/or an established frequency or intensity (e.g., management interventions).

[16] Battaglia, M., & Sands, P. (1998) Application of sensitivity analysis to a model of Eucalyptus globulus plantation productivity. Ecological Modelling, 111(2), 237–259. https://doi.org/10.1016/S0304-3800(98)00114-8

[17] Peng, C. (2000) Growth and yield models for uneven-aged stands: Past, present and future. Forest Ecology and Management, 132(2), 259–279. https://doi.org/10.1016/S0378-1127(99)00229-7

[18] Weiskittel, A. R., Maguire, D. A., Monserud, R. A., & Johnson, G. P. (2010) A hybrid model for intensively managed Douglas-fir plantations in the Pacific Northwest, USA. European Journal of Forest Research, 129(3), 325–338. https://doi.org/10.1007/s10342-009-0339-6

[19] Van Oijen M., Rougier J., & Smith R. (2005) Bayesian calibration of process-based forest models: Bridging the gap between models and data. Tree Physiology, 25(7), 915–927. https://doi.org/10.1093/treephys/25.7.915

[20] Miehle P., Battaglia M., Sands P.J., Forrester D.I., Feikema P.M., Livesley S.J., Morris J.D., & Arndt S.K. (2009) A comparison of four process-based models and a statistical regression model to predict growth of Eucalyptus globulus plantations. Ecological Modelling, 220(5), 734–746. https://doi.org/10.1016/j.ecolmodel.2008.12.010

[21] Baker R.E., Peña J.-M., Jayamohan J., & Jérusalem A. (2018) Mechanistic models versus machine learning, a fight worth fighting for the biological community? | Biology Letters. https://royalsocietypublishing.org/doi/full/10.1098/rsbl.2017.0660

[22] Kurth W. (1994) Morphological models of plant growth: Possibilities and ecological relevance. Ecological Modelling, 75–76, 299–308. https://doi.org/10.1016/0304-3800(94)90027-2

4.3. Review of tree-level models

The review started considering individual-tree models from the first criterion in Sect. 4.2, from process-based to hybrid approaches (i.e., excluding fully empirical or machine learning due to their dependence on the conditions in which they are calibrated) and with time resolution not coarser than 1 month. Table 5 list 13 models responding to the searched characteristics.

Name	Class	Temporal resolution	Reference
BALANCE	Process based	Day	Grote & Pretzsch, 2002
DF.HGS	Hybrid	Day	Weiskittel et al., 2010
EMILION	Process based	1/50 Day	Bosc, 2000
FOREST v5.1	Process based	Day	Schwalm & Ek, 2004
FORGEM	Process based	Day	Kramer et al., 2008
GOTILWA	Process based	Hour	Gracia et al., 1999
Hybrid	Process based	Day	Friend et al., 1997
MAESTRO/MAESPA	Process based	Hour	Duursma & Medlyn, 2012
PICUS v1.3	Hybrid	Month	Seidl et al., 2005
PIPEQUAL	Process based	Day	Mäkelä & Mäkinen, 2003
SIMWAL	Process based	Hour	Balandier et al., 2000
TREE-BGC	Process based	Day	Korol et al., 1995
YIELD-SAFE	Process based	Day	van der Werf et al., 2007

References: Grote & Pretzsch (2002) https://doi.org/10.1055/s-2002-25743; Weiskittel et al. (2010) https://doi.org/10.1007/s10342-009-0339-6; Bosc (2000) https://doi.org/10.1051/forest:2000142; Schwalm & Ek (2004) https://doi.org/10.1016/j.ecolmodel.2004.04.016; Kramer et al. (2008) https://doi.org/10.1016/j.ecolmodel.2008.05.004; Gracia et al. (1999) https://doi.org/10.1007/978-3-642-58618-7_12; Friend et al. (1997) https://doi.org/10.1016/S0304-3800(96)00034-8; Duursma & Medlyn (2012) https://doi.org/10.5194/gmd-5-919-2012; Seidl et al. (2005) https://doi.org/10.1093/treephys/25.7.939; Mäkelä & Mäkinen (2003) https://doi.org/10.1016/S0378-1127(03)00152-X; Balandier et al. (2000) https://doi.org/10.1051/forest:2000143; Korol et al. (1995) https://doi.org/10.1139/x95-046; van der Werf et al. (2007) https://doi.org/10.1016/j.ecoleng.2006.09.017

Table 5 Individual tree models reviewed according to listed criteria and choices.

4.4. A review of potential input datasets

4.4.1. Climate input data

Concerning climate information, Copernicus and other authoritative data portals were visited, and Table 6 summarizes the datasets potentially useful for feeding climate sensitive forest models of different types. An extended version of Table 6 is reported in Appendix A2.

Currently, gridded rainfall time series for both historical and future periods are provided respectively by climate reanalysis or other interpolation products from meteorological stations and by model projections, all available on the Climate Data Store (CDS) of the Copernicus Climate Change Service (C3S). For historical to current studies, the use of reanalysis and interpolated observations is particularly desirable since they are regularly updated, although at a different pace, making them extremely suitable for near-operational purposes. For climate projections, besides global scale simulations with many derived products from interpolation-based downscaling, high spatial resolution ensembles are provided by the COordinated Regional Downscaling Experiment (CORDEX) initiative over different global domains (Europe, South America, South East Asia, Australasia of interest for SILVANUS) and including bias-adjusted products (currently only for Europe). For specific regions and function of project’s partners expertise, additional very high-resolution data can be exploited (e.g., Italy from CMCC simulations).

Dataset & link	Spatial resolution	Temporal coverage

ERA5 - hourly	0.25° (native 0.28°)	1959 to present
ERA5 - monthly	0.25° (native 0.28°)	1959 to present
ERA5-Land - hourly	0.10 (native 9 km)	1950 to present
ERA5-Land - monthly	0.10 (native 9 km)	1950 to present
UERRA / CERRA	5.5 km and 11 km	1961-2019 (until July) / 1984 - present
ERA5@2km	2.2km	1989-2020 (currently)
E-OBS	0.1° and 0.25°	1950 to present year -1
Meteorological time series from regional national networks in addressed countries	Point-scale and/or gridded products	Various, depending on each station's functioning period
Local (incl. private) meteorological information from ground instruments/sensors/stations	Point-scale	Function of the selected Pilot area
CMIP5 - daily	Various, model-based	at least 1951 to 2100
CMIP5 - monthly	Various, model-based	at least 1951 to 2100
CMIP6	Various, model-based	at least 1951 to 2100
CORDEX	0.11°, 0.22°, (but also 0.44°)	at least 1951 to 2100
CORDEX-Adjust	0.11° (for Europe)	at least 1971 to 2100
PROJECTIONS@2.2km	2.2km	1989-2050 (currently)
NEX-GDDP-CMIP6	0.25°	1950-2100
WorldClim 2.1	≈1, 5, 10, 20 km	1970-2100
Bioclimind (Bioclimatic Indicators)	0.5°	1969-2099
Climate extreme indices and heat stress indicators derived from CMIP6 global climate projections	Various, model-based	at least 1951 to 2100
Agrometeorological indicators from 1979 to present derived from reanalysis	0.1°	1979 to present
Agroclimatic indicators from 1951 to 2099 derived from climate projections	0.5°	1951-2099
Global bioclimatic indicators from 1979 to 2018 derived from reanalysis	0.5°	1979-2018
Global bioclimatic indicators from 1950 to 2100 derived from climate projections	0.5°	1950-2100
Downscaled bioclimatic indicators for selected regions from 1979 to 2018 derived from reanalysis	1km	1979 to 2018 (ERA5);2001-2018 (ERA5-land)
Downscaled bioclimatic indicators for selected regions from 1950 to 2100 derived from climate projections	1km	1950-2100
Temperature and precipitation climate impact indicators from 1970 to 2100 derived from European climate projections	5km and 0.11°	1970-2100
Water sector indicators of hydrological change across Europe from 2011 to 2095 derived from climate simulations	5km	2011-2095
Hydrology-related climate impact indicators from 1970 to 2100 derived from bias adjusted European climate projections	5km and catchments	1970-2100
Heat waves and cold spells in Europe derived from climate projections	0.1°	From 1986 to 2085
Fire danger indicators for Europe from 1970 to 2098 derived from climate projections	0.11°	1970-2098
Temperature statistics for Europe derived from climate projections	0.10°	1986 – 2085
Essential climate variables for assessment of climate variability from 1979 to present	0.25°	1979 to present
Essential climate variables for water sector applications derived from climate projections	0.5°	1978-2100

Table 6 Spatial resolution and temporal coverage of datasets on climate raw data (yellow cells) and derived indicators (green cell). An extended version of this Table is provided in Appendix A2.

4.4.2. Information sources for other input data

Besides climate data, information on land (soil, water, vegetation) characteristics can be useful to parameterize different type of forest models. Such information is particularly useful when site-specific data, although more accurate, are difficult to find, of low/heterogeneous quality, or with limited spatio-temporal coverage. A first quick scan revealed that land-based parameters such as elevation, intra annual cycle of vegetation cover or occurrence of fires can be retrieved from Copernicus Land Monitoring Service (CLMS) and Copernicus Emergency Management Service (CEMS) products as well as they can be calculated from Copernicus space components imagery. Table 7 below lists the main datasets explored and potentially exploited in SILVANUS.

Dataset	Spatial resolution	Temporal extent/resolution
CLMS (Vegetation products): Fraction of vegetation cover Burnt Area NDVI	300m	2014 to present (PROBA-V+S3/OLCI), 10-days to monthly synthesis, respectively: within 5 days; 3 months after; within 3 days
CLMS (Land Cover products): Land Cover (LC) Corine Land Cover (CLC) High resolution layers (HRL)	100m (LC, CLC) to <20m	From 2015 to 2019, annual (LC); 1990, 2000, 2006, 2012, 2018 (CLC); 2012, 2015, 2018 (HRL)
CLMS (Elevation product and derivatives like slope, curvature etc.) EU-DEM	25 m	Latest dataset/version available
Soil properties (SOILGRIDS; European Soil DataBase raster or vector)	250 m – 1km	Latest dataset/version available
C3S - Fire burned area	250 - 300 m	2001-2020
CEMS - Burnt Area	250 m	2008 to present
MODIS NDVI - EVI	250 m	2000 to present
DEM Italy (elevation and derivatives)	20 m	Latest dataset/version available
Local land/soil/vegetation characteristics from field/aerial survey/measurements	Area/parcel based	Function of the selected Pilot area
Forest management practices/plans	Area/parcel based	Function of the selected Pilot area

Table 7 Spatial resolution and temporal coverage of datasets on land characteristics.

4.5. Concluding remarks and next steps

The first phase of T2.4 concentrated on defining criteria for reviewing climate sensitive forest models, defined as mathematical models that allow simulating forest ecosystems under multiple management options and climate conditions. Such models were first broadly classified according to specific criteria: tree to stand level; single to mixed species, empirical to physically based. Given the necessity to address combine climate change and management bringing possible modifications in the vulnerability and exposure to fires (in terms of available biomass, vegetation dryness etc.), process-based models (PBMs) or hybrid methods (PMB mixed with empirical approaches) were preferred, and with time step between hourly and monthly, to be easily fed by available and reliable climate and vegetation datasets. The FIPAS mobile application will be one of the solutions developed to create mentioned biodiversity datasets. Now the review will continue in three directions: first, stand level models will be considered, giving priority to representation of multi-species interactions; second, the Inventory Tables arranged in the context of T2.3 will be complied with a selection of models and, if any, of related implemented tools, to be then further filtered for final inclusion in the SILVANUS platform; third; 3D visualization models will be also considered for capturing the forest landscape of the pilot demonstration sites.

5. Historical review of forest resilience to wildfires: preparing to data collection

5.1. Context

As part of WP2, the goal of the T2.5 is to review, as well as gather and analyze information from, the historical reports, datasets and other types of information sources available on past forest fires across the demonstration sites in SILVANUS representing 11 countries.
For a comprehensive and representative assessment, existing data on wildfires will be first examined in detail to cover a wide range of fire causes - from more "natural" (weather, climate) to human-/infrastructure-related (negligence, environmental impact, installation of power grid lines for energy distribution) - along with the investigative analysis. Each of the Pilot sites will be also analyzed exploiting the Earth Observation, from Copernicus and other data portals, with the aim to map the transformation of forest landscape after the spread of analyzed wildfires. The T2.5 expected results are the creation of a GIS database of geolocalized information related to each fire event considered. This database will be used to model the demonstration scenarios outlined in WP9.

5.2. Background knowledge and data analysis methods

Among terminology and methodologies to follow in collecting and analyzing information, some potentially useful have been identified during the initial activities of T2.5.
The wildfire factors can be first classified according to existing definitions, like the Decree of the President of the (Italian) Republic of 20 December 2001, Article 8, which identifies predisposing factors and determining causes. In detail, the *Predisposing factors* are defined as all the aspects that favor the ignition and the spread of a fire, e.g.:

- climatic conditions as high temperatures, drought, windiness, low relative humidity, etc.;
- Geomorphology, that are slopes, exposure to solar radiation, etc.;
- vegetational and silvicultural characteristics that are the presence of flammable and/or combustible species, water content, state of maintenance of the forest, etc.

Determining (or triggering) causes are instead those aspects that in a situation defined by predisposing factors can give rise to the immediate development and propagation of fire. The determining causes can be for example, according to the EU macro-classification:

- fire of unknown origin;
- fire of natural origin;
- fire of negligent/accident origin;
- Deliberate, etc.

5.3. Data collection

The work undertaken in T2.1 and T2.2 through the participatory process and systematic guidelines for Questionnaire Tables preparation, presentation to stakeholders, and evaluation (see Sect. 2) represents an indispensable source of information around fires occurred in the past in the Pilot sites, exploiting especially Questionnaire Tables about the current/existing status (S) and in particular Table S1 (*Pilot summary*), S2 (*Key factors to be considered in the Operational Scenario*) and S4 (*Generic Characteristics of the Pilot*), with questions about the type and characteristics of fire and of the most frequent causes.
To further support data collection in T2.5 on the fires occurred in Pilot sites in the last decade (2012-2022), a dedicated template table was produced. Such a table collects some information on the site and first of all on predisposing factors already available from D2.1 Tables, like: Pilot size surface; land cover type (ha of artificial, agriculture, forests and semi-natural areas, wetlands, water bodies, other) also flagging protected vs. non protected areas; elevation; soil (physical, biogeochemical) properties; average tree composition

(hectares and % of broadleaves, coniferous, mixed forests) and characteristics (average DBH and height). New additional useful information from T2.5 surveys refers to topographic attributes (elevation derivatives like slope and aspect); climate classification following Koppen classification[23] and estimating annual precipitation amount, as well as temperature and humidity in the fire season.

Another section of the Table concerns the fire events' characterization, taking from D2.1 Questionnaire Tables some summary information on fires per year, per month (in each year) and on the typical duration of the fire season (from month to month). Additional data to collect in T2.5 are about "burning" characteristics (burnt surface of wooded and non-wooded areas, and tree composition of the former), days of the week and time of fires, fire severity (e.g., through Normalized Burnt Ratio), interventions per year and number of air interventions, and "logistic" information related to availability of water supply and helicopter landing space and to the accessibility of the site (measured in terms of time to intervene).

Concerning the type of fires, they can be distinguished into: underground; ground (surface); crown/canopy; combination; other (to be specified).

Finally, more details can be given on the causes, selecting among the ones shown in Table 8, as harmonized in Camia et al. (2012)[24], that could be further tuned according to Pilots' needs and benefiting of specific country classifications.

[23] Köppen, W. (1900) Versuch einer Klassifikation der Klimate, vorzugsweise nach ihren Beziehungen zur Pflanzenwelt [Attempted climate classification in relation to plant distributions]. Geogr. Z. 6 (593–611), 657–679.

[24] Camia A, Durrant Houston T, San-Miguel-Ayanz J. Harmonized classification scheme of fire causes in the EU adopted for the European Fire Database of EFFIS. EUR 25923. Luxembourg (Luxembourg): Publications Office of the European Union; 2013. JRC80682

CATEGORY	GROUP	CLASS
100 UNKNOWN	100 Unknown	100 Unknown
200 NATURAL	200 Natural	201 Lightning
		202 Volcanism
		203 Gas emission
300 ACCIDENT	300 Accident	301 Electrical power
		302 Railroads (Railways)
		303 Vehicles
		304 Works
		305 Weapons (firearms, explosives, etc.)
		306 Self-ignition (auto-combustion)
		307 Other accident
400 NEGLIGENCE	410 Use of fire	411 Vegetation management
		412 Agricultural burnings
		413 Waste management
		414 Recreation
		415 Other negligent use of fire
	420 Use of glowing objects	421 Fireworks, firecrackers and distress flares
		422 Cigarettes
		423 Hot ashes
		424 Other use of glowing object
500 DELIBERATE	510 Responsible (arson)	511 Interest (profit)
		512 Conflict (revenge)
		513 Vandalism
		514 Excitement (incendiary)
		515 Crime concealment
		516 Extremist
	520 Irresponsible	521 Mental illness
		522 Children
600 REKINDLE	600 Rekindle	600 Rekindle

Table 8 Classes groups and categories of the harmonized fire causes classification scheme.

5.4. Concluding remarks and next steps

The historical review of forest resilience to wildfires in T2.5 started in April 2022 and the initial months have been dedicated to interacting with T2.1/T2.2 for the definition of the data matrix based on the structured representation of forest fire causes, with the help of the regional Civil Protection agency to validate the table, so to optimize the information to be collected about Pilots sites in the next months, avoiding overlaps while instead complementing with data useful to analyze the characteristics and causes of fires occurred. The information collected in T2.5 will also better inform forest modelling activities now shaped through T2.3 and T2.4. In particular, T2.4 and T2.5 can mutually exchange information related to forest, tree, soil, landscape and climatic characterization, merging project-derived and existing sources. Next steps will consist in review, collection, categorization, standardization, and analysis of data from the historical reports on past forest fires (for the decade 2012 - 2022) of the Pilot sites. By August 2023 and February 204, respectively, it is expected the first and final version of the descriptive report, in the form of factsheets and databases, on the categorization of the historical data on past forest fires of the Pilot sites that will support the modeling of demonstration scenarios. The first version will feed the related section of D2.4 on environmentally sustainable, resilient forest models.

6. Conclusions and way forwards

The SILVANUS WP2 has kicked off its activities in the first semester of the project, conducting periodical meetings/exchanges among Tasks to avoid overlaps and to better align and optimize activities.
T2.1 and T2.2 allowed to harmonize and systematize the way to engage stakeholders and collect information about Pilots, besides starting to analyse requirements in terms of needed products from the project's platform. Concerning these products, they should be practicable tools that implement mathematical to non-mathematical procedures, as well as index-based description, of well-consolidated models for forest growth, stand management, firefighting, fire impact mitigation etc. A review about these models and tools was initiated through T2.3 by providing to partners inventory Tables to fill in the next weeks and months, following an incremental approach to embed first results in the MVP by Month 18, with a focus on climate sensitive forest models in T2.4, which was in turn divided in a first concluded part about individual-tree modes, a next one on stand level models and a further one on 3D visualization models. Finally, T2.5 allowed preparing the floor for collecting information about Pilot sites in the context of forest fires occurred in the past, by clarifying terminology about fire risk and its composing (predisposing vs. determining) factors and arranging a Table – also relying on D2.1 Database – to be compiled with details on occurred events in the last decade (2012-2022), then to be examined through consolidated investigation techniques.
While T2.1 and T2.2 mainly concluded the foresee activities in the first semester, with possibility of complementing the Database provided together with D2.1 thanks to new or improved information on Pilot sites, T2.3, T2.4 and T2.5 enters the crucial period of their development, expected to provide first inputs for the MVP at Month 18, and advanced results at Month 24 through D2.4. The last six months of the WP2 (from Month 25 to Month 30) will be exploited for feedback and exchanges with other WPs, in particular with those related to the SILVANUS platform's development and its first releases.

7. Appendix A1 – Table of model inventory categories

Code	System	Scope	Model Category - Knowledge Field	Nature of Model			Use in Phase		
				Mathematical	Non mathematical (e.g. processes, knowledge, decision methodology)	Index / Indices	A	B	C
M11	DSS Firefighting	Firefighting and Training	Strategies/methodologies for resource deployment and management tactics	+	+	+	Training Forest resilience	Firefighting	
M21	DSS for firefighting	Fire simulator	Fire behavior models: All models relevant to fire behavior prediction such as, surface fire, crown fire, fire transmission to crown, fuel humidity estimation	+			Training Forest resilience	Firefighting	
M22	DSS for firefighting	Fire simulator	Models for Canopy fuel load estimation: All types of models, such as, allometric equations, remote sensing methodologies etc.	+			Training Forest resilience	Firefighting	
M23	DSS for firefighting	Fire risk assessment	Models, methodologies and indices for fire risk assessment and fire damage estimation	+	+	+	Training Forest resilience	Firefighting	Fire impact mitigation
M24	DSS for firefighting	Fire simulator	Models of surface fuel load	+		+	Training Forest resilience	Firefighting	
M31	DSS for firefighting and Forestry DSS	Fire simulator and fuel management	Forest stand models that represent and predict forest stand structure and its characteristics through time, especially, those that calculate stand basal area and individual	+			Training Forest resilience	Firefighting	

		; Forestry DSS	tree diameter. - These models will used for crown fuel load estimation. Also: 3D graph modelling, Use of SIBYLA.						
M41	DSS for firefighting	Fire risk assessment	Models for climate change impact on forests: especially those of forest management adaptation to climate change impact on forests	+	+	+	Training Forest resilience	Firefighting	Fire impact mitigation
M42	DSS for firefighting	Fire simulator	Models for calculation of local weather conditions, especially those that calculate air velocity and direction according to local topography	+		+	Training Forest resilience	Firefighting	
M43	DSS for forest resilience and fire impact mitigation	Fire risk assessment	Models to estimate the effect of environmental factors on forest susceptibility to fire, e.g. climate, attacks from insects, pathogens and parasites	+	+	+	Training Forest resilience	Firefighting	Fire impact mitigation
M51	DSS for firefighting and DSS for forest resilience and fire impact mitigation	Fire risk assessment	Models/Knowledge/Indices for predicting wildfire ignition	+	+	+	Training Forest resilience	Firefighting	Fire impact mitigation
M61	DSS for forest resilience and fire impact mitigation	Fire risk resilience	Models/Knowledge/Indices for wildfire prevention, where areas at high risk of wildfire can be treated and protected from ignitions throughout the peak fire season.	+	+	+	Training Forest resilience		Fire impact mitigation

			Refers to forest management practices to prevent ignition and reduce fire dynamic.						
M62	DSS for forest resilience and fire impact mitigation	Fire risk resilience and mitigation	Models/Indices of biodiversity index and ecological site classification. Models for ecosystem development & forest growth could be relevant.	+	+	+	Training Forest resilience		Fire impact mitigation Reforestation
M63	DSS for forest resilience and fire impact mitigation	Fire risk resilience and mitigation	Models/Knowledge/Indices for development of the forest and landscape management alternatives for fire forest resilience and mitigation of fire impact (soil protection, flood reduction) for specific regions considering the information on biodiversity index and ecological site classification. Include also forest rehabilitation & restoration models and methodologies	+	+	+	Forest resilience		Fire impact mitigation Reforestation
M71	DSS for fire fighting	Protection of population	Models and/or indices that estimate air quality during the fire and risk for human health	+	+	+	Simulation Training	Citizens protection	Mitigation of fire impact to population
M72	DSS for fire fighting	Fire event management (Protection of population)	Models/methodologies to simulate and support evacuation needs due to fire event	+	+	+	Training	Citizens protection	
M81	DSS for forest resilience and fire	Resilience/ Mitigation	Models/indices for soil erosion	+		+			Mitigation

	impact mitigation								
M82	DSS for forest resilience and fire impact mitigation	Resilience/ Mitigation	Models/indices Hydraulics [e.g., runoff, supply-stereo supply curves (Q-Qs curves), sediment discharge rating curves]	+		+	Resilience		Mitigation
M83	DSS for forest resilience and fire impact mitigation	Resilience/ Mitigation	Hydrogeological(infiltration, percolation or filtration etc.)	+		+	Resilience		Mitigation
M84	DSS for forest resilience and fire impact mitigation	Resilience/ Mitigation	Geomorphological - Topographic models/Indices (altitude curve = Hypsometric Curve, branching ratio = bifurcation ratio, hydrographic network texture = drainage texture, drainage area, slopes and branches, etc.)	+		+	Resilience		Mitigation
M85	DSS for forest resilience and fire impact mitigation	Resilience/ Mitigation	Soil quality Indices (e.g., soil texture, total carbon, organic matter, pH, nutrients, pollutants)	+		+	Resilience		Mitigation
M86	DSS for forest resilience and fire impact mitigation	Resilience/ Mitigation	Desertification indices	+		+	Resilience		Mitigation

-M87	DSS for forest resilience and fire impact mitigation	Mitigation of risk assessment	Model/indices for wildfire impact on climate	+	+	+	Resilience		Mitigation

8. Appendix A2 – Table of forest model datasets

Type	Dataset & link (1)	macro-category	spatial coverage (2)	spatial resolution (3)	temporal coverage (4)	temporal resolution (5)	Variables/Indicators	Note
Raw variables	ERA5 - hourly	Reanalysis	Globe	0.25° (native 0.28°)	1959 to present	time series: hourly	Many	
	ERA5 - monthly	Reanalysis	Globe	0.25° (native 0.28°)	1959 to present	time series: monthly	Many	
	ERA5-Land - hourly	Reanalysis	Globe only land	0.10 (native 9 km)	1950 to present	time series: hourly	Many	produced by replaying the land component of the ECMWF ERA5 climate reanalysis
	ERA5-Land - monthly	Reanalysis	Globe only land	0.10 (native 9 km)	1950 to present	time series: monthly	Many	produced by replaying the land component of the ECMWF ERA5 climate reanalysis
	UERRA / CERRA	Reanalysis	Europe	5.5 km and 11 km	1961-2019 (jul) / 1984-present	time series: six hourly / three hourly	Main (temperature, wind, relative humidity, cloud cover, precipitation, snow, pressure)	derived from UERRA-HARMONIE and MESCAN-SURFEX systems / HARMONIE-ALADIN system
	ERA5@2km	Downscaling of ERA5	Italy	2.2km	1989-2020 (currently)	time series: hourly	Main (temperature, dew point temperature, precipitation, wind, pressure, specific humidity, cloud cover, Surface Evaporation, radiation, snow, soil water content)	downscaling of ERA5 from 31 to 2.2 km

	E-OBS	Interpolated observations	Europe	0.1° and 0.25°	1950 to present year -1	time series: daily	Main (temperatures, precipitation, realtive humidity, precipitation, pressure, radiation, wind)	Interpolation from point stations
	Meteorological time series from regional national networks in addressed countries	Observations	Depend on station network	Point level	Depend on single stations	Depend on station (usually at least daily publicly available data)	Main meteorological variables (esp. temperatures, precipitation)	An example is SCIA-ISPRA (http://www.scia.isprambiente.it/) for Italy. It is available at point and gridded level (5 km for temperature, 10 km for precipitation). The temporal coverage is 1981-2013 for gridded daily temperature, 1961-2010 for gridded daily precipitation. Diverse are temporal coverages for daily temperature/precipitation gauges.
	Local (incl. private) meteorological information from ground instruments/sensors/stations	Observations	Depend on station network	Point level	Depend on single stations	Depend on station and instruments	Main (temperature, precipitation, wind, radiation, relative humidity)	
	CMIP5 - daily	Projections (historical to RCP)	Globe	various based on the model	at least 1951 to 2100	time series: daily	Main (temperature, precipitation, snow, wind, radiation, relative and specific humidity, pressure)	Available time coverage depending on the experiment considered
	CMIP5 - monthly	Projections	Globe	various based on the model	at least 1951 to 2100	time series: monthly	Many	Available time coverage depending on the experiment considered

		(historical to RCP)						
	CMIP6	Projections (historical to RCP/SSP)	Globe	various based on the model	at least 1951 to 2100	time series: daily to monthly	Many	Available time coverage depending on the experiment considered
	CORDEX	Projections (historical to RCP)	Europe, Mediterranean, Australasia, South America, south East Asia	At least 0.11° (EURO/MED) and 0.22° (OTHER)	at least 1951 to 2100	time series: sub-daily to seasonal (depending on the region)	Many	Driven by CMIP5
	Cordex-Adjust	Projections (historical to RCP)	Europe	0.11°	at least 1971 to 2100	time series: daily to monthly	temp (min, max, mean), precip, wind speed, Surface Downwelling Shortwave Radiation	Driven by CMIP5 and then bias-corrected
	PROJECTIONS@2.2km	Projections (historical to RCP8.5)	Italy	2.2km	1989-2050 (currently)	time series: hourly	Main (temperature, dew point temperature, precipitation, wind, pressure, specific humidity, cloud cover, Surface Evaporation, radiation, snow, soil water content)	downscaling of COSMO-CLM projections over Italy at 8km
	NEX-GDDP-CMIP6	Projections (historical	Globe	0.25°	1950-2100	time series: daily	Main	downscaled CMIP6

		to RCP/SSP)						
Derived Indicators (for regional dataset considered only those with resolution finer than 0.5°)	WorldClim 2.1	Projections (historical to RCP/SSP)	Globe only land	1 km , 5 km, 10 km, 20 km	1970-2100	climatological means for 20/30 year periods (1970-2000, 2021-2040, 241-2060, 2061-2080, 2081-2100)	tmax, tmin, precip, 19 bioclimatic indicators, + other variables for the historical period	climatological monthly (for tmax, tmin, precip & other variables) and annual (for bioclimatic indicators) mean
	Bioclimind (Bioclimatic Indicators)	Projections (historical to RCP)	Globe only land	0.5°	1969-2099	climatological means for 40 year periods (1969-1999, 2040-2079, 2060-2099)	worldclim indicators + others	climatological annual mean
	Climate extreme indices and heat stress indicators derived from CMIP6 global climate projections	Projections (historical to RCP/SSP)	Globe	various based on the model	at least 1951 to 2100	Yearly, monthly, daily depending on the index	Many indices	Based on CMIP6 (also bias-corrected)
	Agrometeorological indicators from 1979 to present derived from reanalysis	Reanalysis (ERA5)	Globe only land	0.1°	1979 to present	Daily	Main	Based on ERA5
	Agroclimatic indicators from 1951 to 2099 derived from climate projections	Projections (historical to RCP)	Globe only land	0.5°	1951-2099	Non overlapping 30 year period average (Variable dependent: 10-day, seasonal or annual): 1951-1980; …; 2071-2099	Many indicators	Based on ISIMIP

	Global bioclimatic indicators from 1979 to 2018 derived from reanalysis	Reanalysis (ERA5)	Globe	0.5°	1979-2018	Monthly, annual and 40-year (1979-2018) average	worldclim indicators + others	Based on ERA5
	Global bioclimatic indicators from 1950 to 2100 derived from climate projections	Projections (historical to RCP)	Globe	0.5°	1950-2100	monthly, annual and 20-year climatology (for 1961-1980, 1981-2000, 2021-2040, 2041-2060, 2061-2080, 2081-2100)	worldclim indicators + others	Based on bias-adjusted CMIP5
	Downscaled bioclimatic indicators for selected regions from 1979 to 2018 derived from reanalysis	Reanalysis (ERA5 & ERA5-land)	Europe	1km	1979 to 2018 (ERA5);2001-2018 (ERA5-land)	ERA5 - 40-year average (1979-2018), ERA5-Land - 18-year average (2001-2018)	worldclim indicators + others	Input ERA5 and ERA5-Land
	Downscaled bioclimatic indicators for selected regions from 1950 to 2100 derived from climate projections	Projections (historical to RCP)	Europe	1km	1950-2100	climatological means for 20 year periods (1961-1980, 1981-2000, 2021-2040, 2041-2060, 2061-2080, 2081-2100)	worldclim indicators + others	Based on downscaled and bias-adjusted CMIP5
	Temperature and precipitation climate impact indicators from 1970 to 2100 derived from European climate projections	Projections (historical to RCP/degre	Europe	5km and 0.11°	1970-2100	Daily and 30 year annual and monthly means: 1971-2000; 2011-2040;	some precipitation/temperature based	Based on EURO-CORDEX (both bias-adjusted and not)

		e scenarios)				2041-2070; 2071-2100		
	Water sector indicators of hydrological change across Europe from 2011 to 2095 derived from climate simulations	Projections (historical to RCP)	Europe	5km	2011-2095	30 year (monthly and seasonal) averages calculated with a 5-year time-step	Main for the water cycle	Based on bias-corrected CMIP5 model forcing four hydrological models
	Hydrology-related climate impact indicators from 1970 to 2100 derived from bias adjusted European climate projections	Projections (historical to RCP/degree scenarios)	Europe	5km and catchments	1970-2100	Daily and 30 year annual and monthly means: 1971-2000; 2011-2040; 2041-2070; 2071-2100	Main for the water cycle	Based on bias-adjusted EURO-CORDEX model forcing hydrological models
	Heat waves and cold spells in Europe derived from climate projections	Projections (historical to RCP)	Europe	0.1°	From 1986 to 2085	Year (season average), 30-year running average 1971-2100	cold spell, heat wave days	Based on bias-adjusted EURO-CORDEX
	Fire danger indicators for Europe from 1970 to 2098 derived from climate projections	Projections (historical to RCP)	Europe	0.11°	1970-2098	Daily to annual	fire related	Based on EURO-CORDEX
	Temperature statistics for Europe derived from climate projections	Projections (historical to RCP)	Europe	0.10°	1986 – 2085	30 year (winter, summer, annual) running average 1971-2100	tmax, tmin, tmean	Based on bias-adjusted EURO-CORDEX
	Essential climate variables for assessment of climate	Reanalysis (ERA5)	Globe	0.25°	1979 to present	Monthly series and Climatology 1981-2010; 1991-2020,	Surface air temperature, Surface air relative humidity, 0-7cm volumetric soil	Based on ERA5

	variability from 1979 to present						moisture, Precipitation, Sea-ice cover	
	Essential climate variables for water sector applications derived from climate projections	Projections (historical to RCP)	Globe only land	0.5°	1978-2100	time series: daily	tmax, tmin, tmean, precip flux	Based on bias-adjusted CMIP5