1.1. The project summary

Project Number [1]	101003876	Project Acronym [2]	CLINT

One form per project

General information	
Project title [3]	CLImate INTelligence: Extreme events detection, attribution and adaptation design using machine learning
Starting date [4]	01/07/2021
Duration in months [5]	48
Call (part) identifier [6]	H2020-LC-CLA-2020-2
Topic	LC-CLA-12-2020 Advancing climate services
Fixed EC Keywords	Artificial intelligence, intelligent systems, multi agent systems, Detection and attribution of extreme events using Artificial Intelligence, Climate change adaptation, Climatology and climate change
Free keywords	Machine learning

Abstract [7]

Weather and climate extremes pose challenges for adaptation and mitigation policies as well as disaster risk management, emphasizing the value of Climate Services in supporting strategic decision-making. Today Climate Services can benefit from an unprecedented availability of data, in particular from the Copernicus Climate Change Service, and from recent advances in Artificial Intelligence (AI) to exploit the full potential of these data. The main objective of CLINT is the development of an AI framework composed of Machine Learning (ML) techniques and algorithms to process big climate datasets for improving Climate Science in the detection, causation and attribution of Extreme Events, including tropical cyclones, heatwaves and warm nights, and extreme droughts, along with compound events and concurrent extremes. Specifically, the framework will support (1) the detection of spatial and temporal patterns, and evolutions of climatological fields associated with Extreme Events, (2) the validation of the physically based nature of causality discovered by ML algorithms, and (3) the attribution of past and future Extreme Events to emissions of greenhouse gases and other anthropogenic forcing. The framework will also cover the quantification of the Extreme Events impacts on a variety of socio-economic sectors under historical, forecasted and projected climate conditions by developing innovative and sectorial AI-enhanced Climate Services. These will be demonstrated across different spatial scales, from the pan European scale to support EU policies addressing the Water-Energy-Food Nexus to the local scale in three types of Climate Change Hotspots. Finally, these services will be operationalized into Web Processing Services, according to most advanced open data and software standards by Climate Services Information Systems, and into a Demonstrator to facilitate the uptake of project results by public and private entities for research and Climate Services development.

1.3.3. WT3 Work package descriptions

Work package number [9]	WP1	**Lead beneficiary** [10]	1 - POLIMI
Work package title	Project Management and Coordination		
Start month	1	**End month**	48

Objectives

The aim of this WP is to create and maintain the conditions to ensure the effective and timely implementation of project goals. It will facilitate clear and effective flow of information between consortium members and assure the efficient implementation of project activities with involvement of all partners. This WP has three main objectives:
• To ensure the quality and punctuality of scientific outputs;
• To monitor progress of the planned activities and anticipate as much as possible potential shortfalls and address any problems;
• To organize regular meetings of the Management Board and ensure timely interactions with the EU and the project Advisory Board.
It does so by managing the project at 3 levels: strategic/operational, administrative and risk management. The entities involve are (see also Figure 6): The Project Coordinator, the Management Board (WP leaders) and General Assembly (Project PIs), and the Advisory Board.

Description of work and role of partners

WP1 - Project Management and Coordination [Months: 1-48]
POLIMI, CMCC, HZG, CSIC, SMHI, HKV, E3M, TCDF, DKRZ, IHE, ECMWF, UAH, JLU, OGC, UCM
Task 1.1: Strategic and operational management [months 1-48] – POLIMI, ALL
This task involves the scientific coordination of work between WPs and partners, overseeing the efficient and timely flow of information within the consortium, and project integration. It will also perform Quality Assurance and Control of methods, outcomes, reports and deliverables. It will coordinate the preparation of all required periodic activity and management reports, including project reviews for the EC, summarising progress on project tasks, deliverables, and budget usage and reporting any deviations and corrective actions put in place. Three reporting periods are implemented at M18, M30 and M48. Finally, this task will also involve organizing project meetings (kick-off, General Assemblies) as well as Management Board meetings. The outcomes of this task will be reported in Deliverables D1.1-1.2-1.3-1.4-1.5.

Task 1.2: Administrative and financial management [months 1-48] – POLIMI, ALL
Administrative coordination and financial management involve the execution of the overall administrative, legal, and financial responsibilities of the Coordinator as well as covering the communication with and reporting to the EU project officer. More specifically, this coordination will include the following tasks:
• To coordinate the formation of a Consortium Agreement on data exchange, Intellectual Property Rights and the decision taking structure of the consortium;
• To collect legal, administrative, and financial documentation from the partners;
• To chair formal meetings of the project bodies;
• To operate the financial management of the project;
• To manage communication between the contractors and the EC.

Task 1.3: Risk Management [months 1-48] – POLIMI, ALL
This task will review project risks, potential conflicts which may arise during project implementation and produce conflict resolution procedures to manage these. This task will result in the production of the risk management plan and it will also continuously monitor the project environment to detect any risk or contingency, and to prompt countermeasures.

Task 1.4: Coordination/synergies with relevant EU projects and other initiatives [months 1-48] - CMCC, ALL
This task will take care of clustering activities (e.g., H2020 clusters on Climate Services and Earth Observation, WEF Nexus) to promote federation and create synergies with other EU and international projects, also including the participation to meetings organized by the European Commission to promote the outputs of the project. The outcomes of this task will be reported in Deliverable D1.6.

Participation per Partner

Partner number and short name	WP1 effort
1 - POLIMI	15.00
2 - CMCC	3.00
3 - HZG	2.00
4 - CSIC	2.00
5 - SMHI	2.00
6 - HKV	1.00
7 - E3M	1.00
8 - TCDF	1.00
9 - DKRZ	1.00
10 - IHE	2.00
11 - ECMWF	1.00
12 - UAH	1.00
13 - JLU	1.00
14 - OGC	1.00
15 - UCM	1.00
Total	35.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D1.1	Project Management Plan	1 - POLIMI	Report	Public	3
D1.2	First project meeting minute collection	1 - POLIMI	Report	Confidential, only for members of the consortium (including the Commission Services)	12
D1.3	Second project meeting minute collection	1 - POLIMI	Report	Confidential, only for members of the consortium (including the Commission Services)	24
D1.4	Third project meeting minute collection	1 - POLIMI	Report	Confidential, only for members of the consortium (including the Commission Services)	36
D1.5	Fourth project meeting minute collection	1 - POLIMI	Report	Confidential, only for members of the consortium (including	48

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
				the Commission Services)	
D1.6	Project networking report	2 - CMCC	Report	Confidential, only for members of the consortium (including the Commission Services)	48

Description of deliverables

The deliverables will report about the project management structure, including the financial part, and networking activity. All the project report minutes involving decisions and actions will be included in a report, one per reporting period.

D1.1 : Project Management Plan [3]

Report from T1.1 describing the decision-making structures and procedures adopted in the process; the review quality procedures; the management processes to be implemented in steering each WP and task; the financial and resource use reporting guidelines.

D1.2 : First project meeting minute collection [12]

Report from T1.1 collecting minutes of the first year of meetings of advisory boards, general assemblies and any other meeting where decisions are taken, including the kick off meeting.

D1.3 : Second project meeting minute collection [24]

Report from T1.1 collecting minutes of the second year of project meetings of advisory boards, general assemblies and any other meeting where decisions are taken.

D1.4 : Third project meeting minute collection [36]

Report from T1.1 collecting minutes of the third year project meetings of advisory boards, general assemblies and any other meeting where decisions are taken

D1.5 : Fourth project meeting minute collection [48]

Report from T1.1 collecting minutes of the fourth year project meetings of advisory boards, general assemblies and any other meeting where decisions are taken

D1.6 : Project networking report [48]

The deliverable from T1.4 describes all the activities and initiatives to promote coordination with relevant H2020 and other international projects as well as participation in EU project clusters and networking initiatives.

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification

Work package number [9]	WP2	**Lead beneficiary** [10]	1 - POLIMI
Work package title	Climate Intelligence		
Start month	9	**End month**	39

Objectives

The aim of this WP is to develop AI techniques, and specifically ML algorithms, for supporting the detection (WP3), causation (WP4) and attribution (WP5) of EE by efficiently processing big climate datasets and discovering spatial and temporal patterns and evolutions of climatological fields associated with EE. The WP will build on state-of-the-art and develop novel ML algorithms for mining big climatological dataset over different spatio-temporal scales based on the requirements specified by WP3-7. These ML techniques will be supervised methods in the majority of cases, in such a way that atmospheric/oceanic drivers can be linked with their associated extreme events in all cases and specific problems considered. This implies the necessity of labelled datasets, in which extreme events are identified, so ML techniques can be trained and applied to the identification, characterization and possible attribution of extreme events or future events. Unsupervised ML techniques could be used sporadically to reduce computational cost of some approaches when considering a large amount of input data in synoptic-scale events or drivers, to study extreme events with some specific characteristics of the drivers, or to automatically labelled extreme events in problems where obtaining a labelled dataset is difficult or it is not available.
The overall WP goal can be disaggregated into the following specific objectives:

- To develop advanced feature extraction algorithms for EE detection;
- To develop advanced data-driven causal inference algorithms for EE causation analysis;
- To develop advanced neural computation algorithms for EE attribution;
- To develop advanced data-driven models for EE forecasting;
- To develop advanced spatial predicting models for reconstructing past EE.

Description of work and role of partners

WP2 - Climate Intelligence [Months: 9-39]
POLIMI, CMCC, HZG, CSIC, SMHI, TCDF, DKRZ, IHE, UAH, JLU
Task 2.1: Machine Learning for detection of Extreme Events [months 9-39] – POLIMI, UAH, CMCC, IHE, HZG, JLU
The detection of EE requires the identification of spatial and temporal patterns and evolutions of climatological fields (e.g., temperature) associated with EE. This task will design and develop advanced feature extraction techniques, possibly coupled with dimensionality reduction algorithms that can support the detection of EE and the analysis of large datasets of candidate variables monitored over a wide spatial and temporal scales. This data-mining of large climatological fields will allow uncovering possible asymmetric relationships that are often overlooked in traditional EE detection procedures because the variables that better inform the detection of EE might be outside the spatial and temporal domains traditionally monitored. This task builds on recent advances in ML models such as convolutional neural networks or gradient boosted decision trees that will be selected depending on the distinct features of the EE (including compound events and concurrent EE) to be detected in WP3, such as number of observations, frequency of occurrence, spatial and temporal scales. The outcomes of this task will be reported in Deliverables D2.1 and D2.3.

Task 2.2: Machine Learning for causation analysis [months 13-39] – POLIMI, UAH, HZG, CMCC, JLU
Since the ML-based detection of EE in T2.1 discovers relationships between climatological fields and EE from data, the detected teleconnection should be validated to verify the existence of causal relationships rather than spurious numerical correlations. Data-driven causal inference methods can be useful in identifying relevant variables from a generally extremely large number of potential drivers that may be related to the detected EE that entails also concurrent EE. In order to support the ML causation analysis in T4.2, this task will develop data-driven causal inference algorithms whose outputs will be validated against the results of the traditional, physically-based causation analysis run in T4.1. The task will build on state-of-the-art methods, including Layer-wise Relevance Propagation, Bayesian Networks, or the PCMCI method. It will also design novel algorithms based on the estimation of the directed information to address some existing challenges for the application of data-driven causal inference to EE, such as non-stationarity and non-linearities, under-sampling of the processes of interest, or presence of unmeasured variables that create associations among measured variables. The outcomes of this task will be reported in Deliverables D2.1 and D2.3.

Task 2.3: Machine Learning for attribution and future changes of Extreme Events [months 9-39] – UAH, POLIMI, CSIC, CMCC, HZG

The aim of this task is to discover attributable cause-effect relationships between EE and anthropogenic forcing, both on historical records and future climate change conditions. The problem of attribution of EE to drivers at large-scale is extremely hard, due to the large spatio-temporal heterogeneity in the dependencies between EE and candidate drivers. This task will rely on advanced neural computation approaches, such as Extreme Learning Machines or banks of neural networks, that will be trained over transient climate conditions (pre-industrial simulations, historical runs, and climate change projections) to search for trends in EE that can be attributed to anthropogenic effects (T5.2) and to infer relationships between future changes in EE and their drivers (T5.3). The outcomes of this task will be reported in Deliverables D2.1 and D2.3.

Task 2.4: Machine Learning for Extreme Events forecasting [months 13-35] – IHE, POLIMI, SMHI, TCDF, JLU
The aim of this task is the generation of fully data-driven forecasts of EE that do not rely on climate models but, rather, are constructed via ML-based prediction and classification. The data-driven models will be developed according to the results of the EE detection (WP3 and T2.1) after the validation provided by the causation analysis (WP4 and T2.2), taking advantage of potential lag times between the precursors of an EE and its occurrence. The specific requirements in terms of spatial and temporal scales, variables to predict, and relevant lead-times will be mostly determined by the specifics of the use cases in WP6-7, where forecasts will be used to inform decision-making, early warnings, and adaptive capacity at different spatial scales. Particular emphasis will be dedicated to the investigation of both forecast skill and value across different lead-times. This task will rely on state-of-the-art ML models including gradient-boosted regression and trees, Long Short-Term Memory networks, deep neural networks, methods of spatio-temporal analysis, and information theory. The spatio-temporal scale of the EE to predict will be key in order to select the most suitable ML learning techniques. The outcomes of this task will be reported in Deliverable D2.2.

Task 2.5: Machine Learning for reconstruction of past Extreme Events [months 9-35] – DKRZ, POLIMI, CSIC
One major challenge in the analysis of EE is the limited climate information about past EE due to missing values in existing observational records. This task aims at enhancing traditional extreme indices datasets to clear the view on past, present, and future EE by developing novel ML algorithms for spatial prediction or reconstruction of missing values based on image inpainting using deep convolutional neural networks. The algorithms will be developed for relevant EE variables (temperature and precipitation) and time-scales (up-to daily scale) to generate re-filled data sets and indices for supporting the detection, causation and attribution of EE in WP3-4-5. The developed algorithms will be specifically applied in T5.2 for quantifying missing values in existing data sets and estimate their impacts in terms of structural biases in climate trend evaluations and pattern irregularities. Moreover, it will help in discovering EE trends in current day and future climate change scenarios. The outcomes of this task will be reported in Deliverable D2.2.

Participation per Partner

Partner number and short name	WP2 effort
1 - POLIMI	42.00
2 - CMCC	8.00
3 - HZG	14.00
4 - CSIC	4.00
5 - SMHI	2.00
8 - TCDF	2.00
9 - DKRZ	10.00
10 - IHE	17.00
12 - UAH	20.00
13 - JLU	4.00
Total	123.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D2.1	Review of ML algorithms for Climate Science	1 - POLIMI	Report	Public	17
D2.2	ML algorithms for EE forecasts and reconstruction	10 - IHE	Report	Public	34
D2.3	ML algorithms for Climate Science	12 - UAH	Report	Public	38

Description of deliverables

The WP will deliver three reports covering the state of the art of Machine Learning and Artificial Intelligence to support climate science, and illustrating the main WP outputs in terms of methods and tools developed to EE forecast and data infilling as well as to perform detection, causation and attribution of EE.

D2.1 : Review of ML algorithms for Climate Science [17]

Report describing state-of-the-art algorithms developed in the Machine Learning and Artificial Intelligence domain to support climate science in the detection, causation, and attribution of extreme events addressed in T2.1-3.

D2.2 : ML algorithms for EE forecasts and reconstruction [34]

Report from T2.4-5 describing the ML algorithms to generate fully data-driven forecasts of EE, and of the ML algorithms generating spatial predictions or reconstruction of missing values. This report will integrate milestones MS17 and MS22.

D2.3 : ML algorithms for Climate Science [38]

Report from T2.1-3 describing the ML algorithms selected and the new one developed to perform EE detection, causation, and attribution in WP3-5. This report will integrate milestones MS19-20 and MS23.

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS17	First prototype of algorithms for reconstructions of missing EE values	9 - DKRZ	22	This MS is a report about algorithms for reconstructions of missing EE values produced in task T2.5, which will contribute to Deliverable D2.2. Means of verification: Internal report uploaded to the internal project repository
MS19	First prototype of algorithms for EE detection	1 - POLIMI	24	This MS is a report about algorithms for EE detection produced in task T2.1, which will contribute to Deliverable D2.3. Means of verification: Internal report uploaded to the internal project repository

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS20	First prototype of algorithms for EE attribution	12 - UAH	24	This MS is a report about algorithms for EE attribution produced in task T2.3, which will contribute to Deliverable D2.3. Means of verification: Internal report uploaded to the internal project repository
MS22	First prototype of algorithms for EE forecasting	10 - IHE	26	This MS is a report about algorithms for EE forecasting produced in task T2.4, which will contribute to Deliverable D2.2. Means of verification: Internal report uploaded to the internal project repository
MS23	First prototype of algorithms for EE causation	1 - POLIMI	28	This MS is a report about algorithms for EE causation produced in task T2.2, which will contribute to Deliverable D2.3. Means of verification: Internal report uploaded to the internal project repository

Work package number [9]	WP3	Lead beneficiary [10]	2 - CMCC
Work package title	Detection of Extreme Events		
Start month	7	**End month**	41

Objectives

The aim of this WP is to advance traditional Extreme Events detection methods through the ML algorithms and tools developed in WP2 and to generate AI-enhanced S2S forecasts to be assessed in WP6-7. This goal is achieved by two specific objectives:
• Refinement of existing detection techniques/indices using ML to improve existing knowledge of the complex relationships between EE and large-scale fields. This will be done through the identification of large-scale patterns associated with EE conditions, to facilitate the use of model output for S2S and climate projection investigations.
• Development of novel detection techniques/indices using ML to facilitate investigation of EE at both S2S and longer term (centennial) time scales based on products in ECMWF and the CDS platform (ERA5, S2S forecasts, CMIP5/6 simulations).
The WP will focus on three classes of EE (tropical cyclones, heatwaves and warm nights, and extreme droughts). Moreover, as human and natural systems are often able to assimilate a single EE, but might be vulnerable to compound events (i.e., a combination of events, not necessarily extremes, that lead to significant impact) or to concurrent extremes (i.e., different types of EE occurring within a specific temporal lag, either in different and socio-economically linked locations or at the same one, as well as by extremes of the same type in two different locations within a specific time period), the WP will also consider compound events and concurrent extremes.

Description of work and role of partners

WP3 - Detection of Extreme Events [Months: 7-41]
CMCC, POLIMI, HZG, CSIC, SMHI, HKV, TCDF, DKRZ, IHE, ECMWF, JLU, UCM
Task 3.1: Detection of tropical cyclones [months 7-41] – CMCC, ECMWF, POLIMI, IHE
The detection of tropical cyclones (TC) is distributed over three sub-tasks. The outcomes of this task will be reported in Deliverables D3.1-3.2-3.3.
Subtask 3.1.1: Improvement of existing indices for TC detection
Different indices have been developed in the past to derive TC activity based on large-scale fields, including the Genesis Potential Indices (GPI) and the Maximum Potential Intensity indices (MPI). However, no consensus has been yet achieved on the consistency between annual TC count and intensity based on tracking approaches and the aforementioned indices. The aim of this task is to investigate the impact of the different index components (large-scale fields) on the discrepancy between TC activity measures based on tracking and large-scale indices. ML approaches will be applied to the ERA-5 reanalysis and longer time series in a multi-model framework to identify the relative role of each index (GPI or MPI) component. This will help to identify the weight of each large-scale component for TC count (and/or maximum intensity) and temporal variability. In addition, ML algorithms will allow refining the index definition to create ad-hoc indices that better support TC detection. The application of the new indices to model results at different time scales will be performed to support WP6 and WP7.

Subtask 3.1.2: Definition of new key structures for TC genesis
The ability of numerical weather prediction models to predict the genesis of TC on sub-seasonal time-scales varies a lot from case to case, and a knowledge gap exists in the factors influencing the genesis. The aim of this task is to use ML algorithms to identify key aspects of the 3-dimensional atmospheric structure preceding the genesis of TC, such as tropical waves in the atmosphere and ocean heat structure. The selected structures will be independently determined for different parts of the Tropics, and will be then used as a predictor for TC genesis, which will be benchmarked against the prediction of dynamical models on different time scales. The key structures will also give guidance about important systematic errors in the dynamical model that currently harm the prediction of TC genesis.

Subtask 3.1.3: Europe-threatening tropical cyclones in S2S forecasts and climate scenarios
In recent years, several cyclones reached the European west-coast, while being classified as TC almost all the way up to landfall, confirming that climate warming leads to a poleward and eastward extension of the hurricane genesis area. This implies that future hurricanes would be increasingly able to affect Western Europe with strong winds and associated precipitation. At the same time S2S forecasts and climate models have large-scale circulation biases that impact the TC tracks. In this task, ML will be used for the identification of large-scale characteristics leading to a pathway towards

Europe in reanalysis datasets. These characteristics will inform about the risks for extra-tropical transition that would be missed by the TC tracks directly from the model, and will help to suggest warning conditions for Western Europe when concurrent with a developing TC in the tropical Atlantic. The evaluation of changes of the aforementioned conditions under future climate projections will also provide input to T7.3.

Task 3.2: Detection of heatwaves and warm nights [months 7-41] - CMCC, ECMWF, SMHI, HZG, JLU, CSIC, POLIMI, TCDF
In this task, ML techniques will support the detection of heatwaves and warm nights drivers, starting from an initial selection of candidate precursors of extreme near surface daytime and night-time temperatures using process-knowledge and literature. The drivers of the so-defined heat events in this preliminary phase include large-scale fields as well as local land surface variables (e.g., land use, vegetation indices, albedo and soil moisture) that will be identified in observational-based datasets, such as ERA5, but also in historical CMIP6 runs, in order to strengthen the statistics of otherwise rare events. These two complementary sets of local and remote precursors will be then used as inputs for the ML algorithms developed in T2.1, in order to link drivers to predictands, possibly including improved spatial aggregation of the gridded dataset (e.g., via clustering algorithms) to isolate relevant events across the European domain. Finally, ML algorithms from T2.4 will be used to generate S2S forecasts of heatwaves and warm nights for informing WEF Nexus policies and local decision-making in WP6-7. The outcomes of this task will be reported in Deliverables D3.1-3.2-3.3.

Task 3.3: Detection of extreme droughts [months 7-41] – POLIMI, HKV, UCM, JLU, CMCC, SMHI, HZG, CSIC, DKRZ, IHE, TCDF
This task aims at improving the detection of extreme drought events by investigating the relationship between different climatic, meteorological, and hydrological variables over different spatial and temporal scales with their associated impacts, such as reduction of electricity production or crop yield losses and failures. ML algorithms from T2.1 will be applied to support the automatic construction of skilful (highly accurate) and parsimonious (with low input dimensionality) impact-based drought indices. The latter will better link the observed impacts of extreme droughts with the drivers of the event by automatizing and generalizing the variable selection process for the construction of the drought index. The drought episodes diagnosed with these novel indices will be compared with those identified with the more traditional ones to further understand the added value of the former and limitations of the latter. Finally, ML algorithms from T2.4 will be used to generate S2S forecasts of extreme droughts for informing WEF Nexus policies and local decision-making in WP6-7. The outcomes of this task will be reported in Deliverables D3.1-3.2-3.3.

Task 3.4 Compound events and concurrent extremes [months 10-41] – JLU, CMCC, POLIMI
Subtask 3.4.1: Compound events
This sub-task aims at exploiting innovative approaches, based on the AI/ML toolbox developed in WP2, for the detection and characterization of the spatio-temporal evolution of compound events at the EU scale that lead to significant impacts in one or more sectors of the WEF Nexus (WP6). This task will build on existing methods (e.g. copula, multivariate statistics) enhanced with AI/ML methods from WP2. The task will originally focus on three types of compound events, allowing for extension to further applications and events: a) relatively wet and warm late winters together with dry and warm following spring with severe impacts on agriculture (T6.3); b) dry winters followed by hot summers, as accumulating pressure on the agriculture and the energy sector with direct impacts on the hydropower capacities during increased demand period (T6.2); c) wet and warm spring, with impacts on water management, increased flood risk (T6.1) due to precipitation excess and early melting season (e.g., May 1999 in Switzerland), as well as an additional stressor on hydropower reservoirs. The outcomes of this sub-task will be reported in Deliverables D3.1-3.2-3.3.

Subtask 3.4.2: Concurrent extremes
This sub-task focuses on the detection and characterization of the spatio-temporal evolution of concurrent EE at the global scale. Encouraging results have been already obtained , and the hybrid approach, here proposed, could potentially outperform existing methods. Large-scale drought events and heatwaves, leading to heavy impacts on key socio-economic sectors as well as shocks, will be analysed by taking advantage of T 3.2 and T3.3. This task will also give the opportunity to identity and explore teleconnections mechanisms responsible for the identified concurrent EE. This will then serve as a basis for T4.3. Furthermore, this approach will be applied in T5.3 to investigate climate change projections. The outcomes of this sub-task will be reported in Deliverables D3.1-3.2-3.3.

Participation per Partner

Partner number and short name	WP3 effort
1 - POLIMI	11.00
2 - CMCC	32.00
3 - HZG	10.00
4 - CSIC	4.00
5 - SMHI	7.00
6 - HKV	1.00
8 - TCDF	3.00
9 - DKRZ	2.00
10 - IHE	5.00
11 - ECMWF	19.00
13 - JLU	10.00
15 - UCM	2.00
Total	106.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D3.1	Extreme Events detection	11 - ECMWF	Report	Public	18
D3.2	Preliminary AI-enhanced Extreme Events detection	2 - CMCC	Report	Public	30
D3.3	AI-enhanced Extreme Events detection	2 - CMCC	Report	Public	40

Description of deliverables

The WP will deliver three reports integrating multiple contributions prepared as milestones on the different EE. The first report is a review of the state-of-the-art of EE detection and ML application to detection. The second and third documents will report about the CLINT main achievements in improving EE detection via ML.

D3.1 : Extreme Events detection [18]

Report from T3.1-3.4 integrating milestones MS5-11 and reviewing existing knowledge, data and models for EE detection, and, for each category of EEs, identifying indices, datasets, and candidate drivers for ML based detection.

D3.2 : Preliminary AI-enhanced Extreme Events detection [30]

Report from T3.1-3.4 illustrating the preliminary applications of the ML algorithms developed in WP2 to EE detection.

D3.3 : AI-enhanced Extreme Events detection [40]

Report from T3.1-3.4 integrating milestones MS30-34 and illustrating the applications of the ML algorithms developed in WP2 to EE detection, outlining pros and cons for each category of EEs and recommendations to users.

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS5	Climate dataset provision for EE detection analysis	8 - TCDF	12	This MS verifies the provision of climate dataset for EE detection produced in task T3.2. Means of verification: Dataset available in the internal project repository
MS6	Indices for tropical cyclones	2 - CMCC	14	This MS is a report about indices for tropical cyclones produced in task T3.1, which will contribute to Deliverable D3.1. Means of verification: Internal report uploaded to the internal project repository
MS7	Datasets and candidate drivers for tropical cyclones	11 - ECMWF	14	This MS is a report about datasets and drivers for tropical cyclones produced in task T3.1, which will contribute to Deliverable D3.1. Means of verification: Internal report uploaded to the internal project repository
MS8	Datasets and candidate drivers for extratropical transitions	2 - CMCC	14	This MS is a report about dataset and drivers for extratropical transitions produced in task T3.1, which will contribute to Deliverable D3.1. Means of verification: Internal report uploaded to the internal project repository
MS9	Datasets and candidate drivers for heatwaves and tropical nights	2 - CMCC	14	This MS is a report about datasets and drivers for heatwaves and tropical nights produced in task T3.2, which will contribute to Deliverable D3.1. Means of verification: Internal report uploaded to the internal project repository
MS10	Datasets and candidate drivers for extreme droughts	1 - POLIMI	14	This MS is a report about datasets and drivers for extreme droughts produced in tast T3.3, which will contribute to Deliverable D3.1. Means of verification: Internal report uploaded to the internal project repository
MS11	Datasets and candidate drivers for compound events and concurrent extremes	13 - JLU	14	This MS is a report about datasets and drivers for compound events and

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
				concurrent extremes produced in task T3.4, which will contribute to Deliverable D3.1. Means of verification: Internal report uploaded to the internal project repository
MS30	AI improved indices for tropical cyclones	2 - CMCC	38	This MS is a report about AI improved indices for tropical cyclones produced in task T3.1, which will contribute to Deliverable D3.3. Means of verification: Internal report uploaded to the internal project repository
MS31	ML improved detection of tropical cyclones	11 - ECMWF	38	This MS is a report about improved detection of tropical cyclones produced in task T3.1, which will contribute to Deliverable D3.3. Means of verification: Internal report uploaded to the internal project repository
MS32	ML improved detection of heatwaves and warm nights	2 - CMCC	38	This MS is a report about improved detection of heatwaves and warm nights produced in task T3.2, which will contribute to Deliverable D3.3. Means of verification: Internal report uploaded to the internal project repository
MS33	ML improved detection of extreme droughts	1 - POLIMI	38	This MS is a report about improved detection of extreme droughts produced in task T3.3, which will contribute to Deliverable D3.3. Means of verification: Internal report uploaded to the internal project repository
MS34	ML improved detection of compound events and concurrent extremes	13 - JLU	38	This MS is a report about improved detection of compound events and concurrent extremes for tropical cyclones produced in task T3.4, which will contribute to Deliverable D3.3. Means of verification: Internal report uploaded to the internal project repository

Work package number [9]	WP4	**Lead beneficiary** [10]	3 - HZG
Work package title	Causation Analysis and Physical Interpretability of Extreme Events		
Start month	13	**End month**	43

Objectives

Objectives
As ML algorithms are pure data-driven approaches, the interdependencies detected in WP3 between certain EE and their potential drivers might be numerically fortunate but physically meaningless. Indeed, correlation does not imply causation. This WP will put the causality links detected in WP3 to stringent tests. One test is based on the analysis of sets of climate model simulation, in which forcing, coupling schemes, spatial resolution and mean atmospheric states are varied. The second test is based on the application of causality ML-algorithms, some already existing, some designed in WP2, to the ML- models applied in WP3 The objective is to buttress the results obtained in WP3 by a proper physical interpretation, achieving the identification of the true physical chain of events that trigger EE.
Once the knowledge of the causal chain from drivers to EE has been firmly established, WP4 will also exploit the huge synthetic datasets of climate simulations to advance into the riskier but essential field of the probabilistic seasonal forecast (S2S or even longer timescales) of the probability of occurrence of EE. The knowledge so generated will be transferred (in the physical sense and ML-sense) to the observational datasets and the real world. The ideal outcome will be ML-models for 2S2 prediction of EE, robustly validated in long simulations with different climate models.
Thereby, special attention will be paid to the connections between concurrent EE, as these pose the more catastrophic impacts on society. These events can either be driven by the same large-scale anomalies or be causally linked themselves, so that one EE triggers the next one.
WP4, fed with the results obtained in WP2 and WP3, will provide a robust support for detection and attribution analysis of EE in WP5 and, in general, to AI-enhanced forecast and projections of EE. Specifically, WP4 will:
• Provide the physical causal explanation for the relationships identified in WP3 by analysing climate simulations with different forcing, different atmosphere-ocean coupling, different spatial resolutions, different boundary conditions, and nudged towards prescribed atmospheric mean states;
• After identifying a subset of meaningful and physically plausible causal relationships, it will apply ML causality detection algorithms to assess their potential to infer true causation beyond correlation.
• The knowledge gained through the analysis of climate simulations and causality-ML algorithms to the design of ML-models for the probabilistic S2S prediction of EE.

Description of work and role of partners

WP4 - Causation Analysis and Physical Interpretability of Extreme Events [Months: 13-43]
HZG, POLIMI, CMCC, CSIC, SMHI, TCDF, UAH, JLU
Task 4.1: Physical causality from analysis of climate simulations (months 13-43) - HZG, CMCC, CSIC, POLIMI, UAH, SMHI, TCDF, JLU

A comprehensive set of climate simulations will serve as a numerical laboratory to validate the ML algorithms developed in WP2 and applied to the detection of different EE in WP3 (see Box 1 in Part B) to analyse the causal chain of the considered EE. Part of this set of simulations is already available from model intercomparison projects such as CMIP5 (including CORDEX) and CMIP6, Chemistry-Climate Model Initiative (including chemistry), S2S forecasts, or atmospheric stand-alone simulations. The rest of required simulations will be created in WP4 with state-of-the-art global and regional climate models. This set will comprise SST and soil-moisture sensitivity runs, global and regional simulations nudged towards a prescribed mean state (e.g. towards stronger polar vortex). Drops or changes in the predictive skill of ML-models when a driver is modified and/or the assumed causality chain is artificially perturbed in the model runs will rule out or confirm the causes of EE and help encircle the real physical drivers. Similarly, the differences between model versions with and without a well-resolved stratosphere, or between models with and without interactive chemistry, or regional climate models run at very high or medium spatial resolution, will determine whether the stratosphere and/or small-scale processes modulate the causal links. In the case of pairs of concurrent EE, their possible physical interconnection will be ascertained by artificially suppressing the occurrence of one of them in a climate simulation (e.g. precipitation/soil moisture) and detecting a different behaviour in the other EE (e.g. subsequent heatwave). Nudging the atmospheric mean state in a climate simulation will tend to suppress both concurrent EE if they both are driven by the same large-scale circulation pattern. The outcomes of this task will be reported in Deliverables D4.1-4.2.

Task 4.2: Machine-Learning causality analysis in observations and simulations (months 25-43) - UAH, POLIMI, HZG, CMCC, SMHI, JLU
Based on the physical guidance and on the selection of mechanistic chain of events leading to EE and concurrent EE obtained from T4.1, this task will apply the causality-ML algorithms developed in T2.2. to the corresponding ML-models. These causality algorithms may be already available and/or they may be newly developed in WP2. The specific causality-ML algorithms will depend on the type of ML-model used for the detection of particular types of EE in WP3. For neural networks models, there are already relatively well-established algorithms, like Optimal Input, Layerwise Relevance Propagation, Bayesian deep learning, and super-resolution convolutional neural networks. In addition to those algorithms, and also for other non-neural ML-models, this task will rely on algorithmic developments from WP2 or/ and apply more general causality algorithms, like Bayesian Graphical networks. In particular, the causality connection between concurrent EE can be well investigated by general Bayesian networks fed by large datasets, for instance those available from long climate simulations, provided those EE are well represented in global/regional climate models. The outcomes of this task will be reported in Deliverable 4.2.

Participation per Partner

Partner number and short name	WP4 effort
1 - POLIMI	9.00
2 - CMCC	6.00
3 - HZG	18.00
4 - CSIC	7.00
5 - SMHI	6.00
8 - TCDF	3.00
12 - UAH	9.00
13 - JLU	6.00
Total	64.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D4.1	Extreme Events causation analysis	3 - HZG	Report	Public	30
D4.2	AI-enhanced causation analysis	3 - HZG	Report	Public	42

Description of deliverables

The WP will deliver two reports integrating multiple contributions prepared as milestones on the different EE. The first report is a review of the state-of-the-art of EE causation analysis and ML application to causation. The second document will report about the CLINT main achievements in improving EE causation analysis via ML.

D4.1 : Extreme Events causation analysis [30]

Report from T4.1 integrating milestones MS18 and MS24 and reviewing existing knowledge, data and models for physical causation analysis for different EE, including concurrent extremes.

D4.2 : AI-enhanced causation analysis [42]

The deliverable from T4.1-2 integrates milestones MS35-36 and reports on the applications of ML to EE causation analysis, outlining pros and cons for each category of EEs and comparatively analysing physical and ML based causation.

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS18	Candidate causal relationships identified	3 - HZG	22	This MS is a report about the identification of causal relationships produced in task T4.1, which will contribute to Deliverable D4.1. Means of verification: Internal report uploaded to the internal project repository
MS24	Candidate extremes for mutual causality identified	13 - JLU	28	This MS is a report about the identification of extremes for mutual causality produced in task T4.1, which will contribute to Deliverable D4.1. Means of verification: Internal report uploaded to the internal project repository
MS35	Physically validated causal networks for each type of EE	12 - UAH	38	This MS is a report about EE causal networks produced in task T4.2, which will contribute to Deliverable D4.2. Means of verification: Internal report uploaded to the internal project repository
MS36	Identification of concurrent and physically linked European EE	13 - JLU	38	This MS is a report about the identification of concurrent and physically linked European EE produced in task T4.2, which will contribute to Deliverable D4.2. Means of verification: Internal report uploaded to the internal project repository

Work package number [9]	WP5	Lead beneficiary [10]	4 - CSIC
Work package title	Attribution Analysis and Future Projections of Extreme Events		
Start month	7	End month	37

Objectives

This WP will develop process-oriented and ML-based approaches to set on a firm footing the AI-enhanced Climate Science in the physical understanding of EE detected in WP3 (see Box 1 in Part B), their links with anthropogenic forcing and their future changes. This goal will be achieved through the following specific objectives:
• To detect human fingerprints in EE and their drivers by exploiting the ML algorithms (WP2) developed for the detection (WP3) and causation (WP4) of EE. The developed methods will be applied to a selection of historical EE, as provided by WP6-7.
• To advance in the attribution of trends in the spatial patterns of EE and related extreme indices through an improved quantification of observed trends and their associations with anthropogenic forcing by using tailored developments of ML methods.
• To quantify future changes for each class of EE and concurrent EE based on a ML-based identification of robust responses in the drivers of EE across the multi-model ensemble of climate projections. Best- and worst-case scenarios of EE changes will be constructed to inform WP6-8.

Description of work and role of partners

WP5 - Attribution Analysis and Future Projections of Extreme Events [Months: 7-37]
CSIC, POLIMI, CMCC, HZG, SMHI, TCDF, DKRZ, IHE, UAH, JLU
Task 5.1: Attribution of EE [months 7-37] - CSIC, CMCC, UAH, POLIMI, SMHI, TCDF
This task aims at developing event attribution approaches based on AI/ML methods developed in T2.3 to better assess the influence of anthropogenic factors in changing the probability of single EE. 'Unconditional' and conditional (partial) attribution approaches will be developed by using the trained ML algorithms for the detection (WP3) and causation (WP4) of EE in a predictive mode, driven by data from historical simulations of the CDS platform (CMIP5/6) with and without anthropogenic forcing, as well as subperiods of 20th century reanalyses with different levels of anthropogenic forcing. These novel attribution methods will be evaluated in historical EE to test consistency (replication) and stress the added value of AI in current attribution capabilities. They will then be applied to a tailored selection of EE that impacted on the European WEF Nexus in WP6 (see Box 2 in Part B) and the Climate Change Hotspots in WP7 (see Box 3 in Part B) in order to supply relevant information for impact assessments.
For unconditional attribution, the overall changes in the probability of occurrence of EE classes will be quantified from the large-scale patterns realized in historical and natural simulations (or in present and past periods of reanalysis) by using the ML-based regressions between large-scale patterns and EE retrieved from WP3. For conditional attribution, the causation analysis of EE (WP4) will be exploited to assess human influences in the chain of processes affecting a given class of EE. Using partial training / regression of ML algorithms, changes in the probability of EE will be partitioned in those affecting the drivers themselves and their links with the EE, thus isolating human fingerprints in the relevant processes of EE. Recent conditional-attribution methods (e.g. dynamical conditioning of EE) will be used as a benchmark of the developments with the AI framework. The outcomes of this task will be reported in Deliverables D5.1-5.2.

Task 5.2: Attribution of trends in EE [months 13-37] - DKRZ, CSIC, HZG, POLIMI
This task aims at advancing in the detection of observed trends in EE and their related extreme indices (e.g. warm days, warm nights, consecutive dry days, etc.), and their attribution to anthropogenic factors through the ML methods developed in T2.5, that will be applied to reconstruct observed variables like temperature and precipitation on different time scales (daily and monthly). Appropriate observational data sets will get investigated to be compliant with the developed technology and a certain extend into the past – including HadEX3, Berkeley Earth, ECAD, GPCC, ESA-CCI, etc. and if necessary, its underlying sources. We will also explore if ML techniques are adequate for the reconstruction identified patterns of extreme indices (ETCCDI and ET-SCI) and observed trends in EE, which are more challenging due to its irregular spatio-temporal occurrence. For the so-detected trends in observations we will assess their compatibility with trends simulated in historical runs with Earth System Models (CMIP5/6) retrieved from the C3S of the CDS. A suite of ML algorithms (T2.3) will be trained with spatially resolved maps of extreme indices and EE from historical simulations to uncover robust forced patterns without an explicit separation of forced responses from internal variability, which is a major issue in traditional attribution studies. The trained algorithms will then be driven by the observed

infilled patterns to identify the emergence of these forced patterns in observations. ML algorithms trained with a subset of the model ensemble and applied to the remaining members will indicate the level of model agreement and confidence in the attribution of past trends. The comparison with similar diagnostics retrieved from natural-only simulations will further support the attribution to anthropogenic factors. The outcomes of this task will be reported in Deliverable 5.2.

T5.3: Future changes of EE [months 15-37] - CMCC, CSIC, UAH, JLU, SMHI, TCDF, IHE
This task aims at providing more informative projections of future changes in EE through improved understanding of the drivers that govern the projected spread of EE and concurrent EE. Future changes in EE, concurrent EE and their drivers will first be assessed and validated with the ML tools applied in WP3-4 by using multi-model ensembles of climate projections (as retrieved from the C3S of the CDS) and comparing them to their historical simulations. The analysis will focus on periods when specific global warming targets have been reached (including those of the Paris agreement), therefore avoiding the uncertainty of climate sensitivity.
ML techniques developed in T2.3 will be applied to uncover robust responses of EE to changes in their drivers across the multi-model ensemble, quantify nonlinear future responses in the co-occurrence of EE and identify the underlying mechanisms. A manageable number of storylines (plausible outcomes) of future changes in EE will be constructed by creating different (but physically feasible) combinations of drivers' responses and reconstructing the associated changes in EE from the relationships learned by the aforementioned ML tools. High- and low-end storylines for each type of EE will be developed at both the European and subcontinental scales. The subset of models whose drivers' responses match the best with each storyline will be delivered to WP6 in order to yield high- and low-impact scenarios in the WEF Nexus. Storylines will be implemented in WPS developed in WP8 as a demo application of AI-enhanced Climate Science. The outcomes of this task will be reported in Deliverable 5.2.

Participation per Partner

Partner number and short name	WP5 effort
1 - POLIMI	5.00
2 - CMCC	8.00
3 - HZG	9.00
4 - CSIC	20.00
5 - SMHI	6.00
8 - TCDF	3.00
9 - DKRZ	10.00
10 - IHE	2.00
12 - UAH	10.00
13 - JLU	6.00
Total	79.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D5.1	Extreme Events attribution	4 - CSIC	Report	Public	18
D5.2	AI-enhanced attribution and projections of Extreme Events	4 - CSIC	Report	Public	36

Description of deliverables

The WP will deliver two reports integrating multiple contributions prepared as milestones on the different EE. The first report is a review of the state-of-the-art of EE attribution and ML application to attribution. The second document will report about the CLINT main achievements in improving EE attribution via ML.

D5.1 : Extreme Events attribution [18]

The report from T5.1 expands milestone MS16 and reviews existing knowledge, data and models for attribution analysis of different EE.

D5.2 : AI-enhanced attribution and projections of Extreme Events [36]

The deliverable from T5.1-5.2-5.3 integrates milestones MS25-26-27 and reports on the applications of ML algorithms to EE attribution, the detection of observed trends and the construction of future storylines, outlining pros and cons for each category of EE.

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS16	Attribution framework for different types of EE defined	4 - CSIC	16	This MS is a report about the attribution framework produced in task T5.1, which will contribute to Deliverable D5.1. Means of verification: Internal report uploaded to the internal project repository
MS25	Historical EE selected for attribution studies	4 - CSIC	28	This MS is a report about the selection of historical EE for attribution studies produced in task T5.1, which will contribute to Deliverable D5.2. Means of verification: Internal report uploaded to the internal project repository
MS26	Trends in EE detected	9 - DKRZ	32	This MS is a report about trends in EE produced in task T5.2, which will contribute to Deliverable D5.2. Means of verification: Internal report uploaded to the internal project repository
MS27	Storylines of projected changes in each type of EE constructed	2 - CMCC	34	This MS is a report about projected changes in EE produced in task T5.3, which will contribute to Deliverable D5.2. Means of verification: Internal report uploaded to the internal project repository

Work package number [9]	WP6	**Lead beneficiary** [10]	5 - SMHI
Work package title	AI-enhanced Climate Services to Foster Adaptation at the Pan European Scale		
Start month	1	**End month**	48

Objectives

This WP focuses on innovation and enhancement of existing CS and their impact-based products, and consequently on the support of several EU policies in the WEF Nexus. WP6 will use and innovate pan-European complex process-based mechanistic models of the water (E-HYPE hydrological model), energy (PRIMES power supply model), and food (EC-JRC crop model ECroPS and the MARS Crop Yield Forecasting System, MCYFS) systems to characterise, estimate, predict and project impacts driven by EE (see Box 2). A circular interaction between WP6 and previous WP (WP2-5) will ensure continuous exchange and feedback of information (AI-based and AI-enhanced Climate Science) required to achieve tailored developments of the ML techniques. The innovation of these existing systems will not be limited to the integration of novel ML algorithms, but an AI-revolution will be put in place to bring these services to the forefront of CS and finally provide an evolved Climate Service Information Systems in T8.3 to dynamically visualize WP6 outputs. The impact models in all tasks will be driven by state-of-the-art observations, reanalysis data, seasonal forecasts and climate projections, with particular focus on datasets available in C3S through the CDS platform, including high-resolution Euro-CORDEX and CMIP5/6, which will be tailored (downscaled and bias-adjusted) for impact assessments. This modelling effort will set a baseline to compare AI-based (WP2) and AI-enhanced (WP3-5) forecasts and projections and understand the added value on CS, as measured by the differences in the value of the computed indicators listed in Box 2. The evaluation of the AI-enhanced CS and quantification of the added value to existing CS (benchmarks) in terms of impact predictions will follow protocols defined in each task, and will be conducted at the pan-European scale via commonly used evaluation metrics (generic and event-based).
The specific objectives of this WP are to:
• To advance in impact predictions and projections of EE at the European scale through an upgrading of the impact-based models and use of state-of-the-art seasonal forecast systems and climate projections.
• To evolve WEF related CS for future time horizons by taking advantage of AI-enhanced Climate Science to characterise, estimate, predict and project extreme impacts.
• To explore the AI-enhanced CS and products from WP3-5 (e.g. best- and worst- case scenarios of future changes in EE from WP5) to better understand the complex and dynamic interrelationships between water, energy and food (nexus) towards a more coordinated management and use of natural resources across sectors and scales.
• To quantify the added value of developed products and CS through a rigorous evaluation procedure and benchmarking against existing Copernicus products.

Description of work and role of partners

WP6 - AI-enhanced Climate Services to Foster Adaptation at the Pan European Scale [Months: 1-48]
SMHI, POLIMI, CMCC, E3M, TCDF, IHE, JLU
Task 6.1: Enhanced Climate Services for extreme impacts in the water sector [months 1-45] - SMHI, IHE, JLU, POLIMI, TCDF
This task will make use of state-of-the-art hydrological predictions (seasonal and projections) that are implemented in operational Copernicus (C3S and CEMS) services to support the water-relevant sectors. The developments here will encompass defining and merging innovative methodologies and tools developed in WP2-5 to better quantify the impacts of tropical cyclones, extreme droughts and compound events over Europe with a focus on floods and hydrological drought risk (see Box 2). High resolution meteorological and climatological data from several providers (multiple systems of large ensemble sets) will be downscaled and bias-adjusted and used to drive the pan-European E-HYPE hydrological model developed by SMHI to generate the impact indicators on the seasonal time horizon (seasonal forecasts) and current and future climatic conditions (projections). This task will also use AI-based predictions (WP2) and AI-enhanced seasonal forecast and projections (WP3-5) which will be integrated in the impact modelling to quantify the added-value of AI-enhanced products on CS. Large-scale flood and hydrological drought events will be detected and available descriptors and AI/ML tools will further be used to improve the predictability of events including an improved understanding of the drivers that cause extreme impacts. Finally, the task will attribute detected trends in the impact indicators under future conditions to climate change. The outcomes of this task will be reported in Deliverables D6.1-6.2-6.3.

Task 6.2: Enhanced Climate Services for extreme impacts in the energy sector [months 1-45] - E3M, SMHI, JLU, TCDF, POLIMI
This task will enhance the understanding of the effects of EE, i.e. heatwaves, warm nights, and extreme droughts as well as compound events, on the energy sector in seasonal forecasting mode and under current and future climatic conditions. EE seasonal forecasts and projections prepared in WP3-5 will be used to understand the effects on the energy system and the operation of the power generation system in terms of power generation cost, load cuts, and carbon intensity, and comparatively assessed with equivalent state-of-the-art products. For this purpose, the PRIMES model for power generation will include EE in its detailed unit commitment model version PRIMES IEM to assess impact of EE over Europe. The PRIMES model has been used to carry out impact assessments for the European Commission including the Clean Planet for all strategy (2018), the Winter Package in 2016, the Energy Roadmap, the Low Carbon Economy Roadmap, as well as specifically for the Market Design Initiative with the PRIMES-IEM. This work will build on previously undertaken research for DG R&I which analysed the Iberian Peninsula and Danube region and will expand the geographic scope to the entire EU as well as including the effects of EE. The effects on the power generation system (e.g. electricity costs, back-up requirements, etc.) will be analysed. Further, this will be combined with simulation of different demand load curves due to the occurrence of heatwaves and warm nights that lead to higher cooling demand - in most southern European countries the peak demand for electricity is already in summer. The outcomes of this task will be reported in Deliverables D6.1-6.2-6.3.

Task 6.3: Enhance Climate Services for extreme impacts in the food sector [months 1-45] - JLU, SMHI, POLIMI, TCDF
This task will provide an AI-enhanced CS for the European food sector based on the existing crop monitoring, forecasting and projecting systems in place at the European Commission's Joint Research Centre (EC-JRC). The EC-JRC has developed dedicated modelling approaches working at different spatial and temporal scales (with a special focus on Europe) using different sources of data. Within this task, AI-enhanced EE seasonal forecasts and projections produced by WP 3-5 will be integrated and employed on the monitoring and seasonal forecasting system (in support of CAP) and the climate change impact assessment and climate change adaptation systems (supporting the new Green Deal, the Climate Adaptation strategy and the CAP). The final objective of this task is to assess the impact of future changes in EE on the crop production system by analysing and interpreting all available data and computing via model simulation quantitative indicators for the agricultural sector. The focus will be on heatwaves, warm nights and extreme droughts, with emphasis on compound events and concurrent EE, to better quantitatively estimate impacts on crop yield, and to identify the so-called Areas of Concern (i.e. areas affected by events with heavy impacts on agriculture) and new hotspots vulnerable to climate change. The outcomes of this task will be reported in Deliverables D6.1-6.2-6.3.

Task 6.4: Enhancing Climate Services in the European Water-Energy-Food Nexus [months 34-48] – POLIMI, SMHI, E3M, JLU, CMCC
The WEF Nexus has emerged as a useful concept to describe and address the complex and interrelated nature of natural resource systems, on which society depends to achieve different social, economic and environmental goals. The Nexus here will set a conceptual approach to better understand and systematically analyse the interactions between the natural environment and human activities affecting the water, energy and food systems, and to work towards a more coordinated management and sustainable use of natural resources across sectors and scales. This allows exploring trade-offs and building synergies across the Nexus components to support more integrated and cost-effective planning, strategic decision-making, policy implementation, monitoring and evaluation. This task will provide a synthesis of the findings in T6.1-6.3 on AI-enhanced CS and relevant data/indicators in order to better understand and manage the complex interactions between the different Nexus components, generating a better understanding of the needs and gaps of current EU policies about water, energy, and food, their interdependencies, and their vulnerabilities with respect to the EE impacts. The outcomes of this task will be reported in Deliverable D6.4.

Participation per Partner

Partner number and short name	WP6 effort
1 - POLIMI	14.00
2 - CMCC	4.00
5 - SMHI	25.00
7 - E3M	12.00
8 - TCDF	6.00

Partner number and short name	WP6 effort
10 - IHE	5.00
13 - JLU	20.00
Total	86.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D6.1	EU Climate Services on the impacts of Extreme Events	5 - SMHI	Report	Public	12
D6.2	Preliminary report on AI-enhanced Climate Services for extreme impacts	7 - E3M	Report	Public	33
D6.3	AI-enhanced Climate Services for extreme impacts	13 - JLU	Report	Public	44
D6.4	Policy brief - EU Climate Services	1 - POLIMI	Other	Public	48

Description of deliverables

The WP will produce four deliverables. The first will provide an overview of existing CS at the EU level and identify space for improvements of existing services or for new services. The second and third will illustrate the new AI enhanced services generated by and assessed in CLINT; the second is a preliminary report to illustrate the preliminary analysis. The last deliverable is a policy brief to inform the EU stakeholders, EU policy makers, and the public about the WP main findings.

D6.1 : EU Climate Services on the impacts of Extreme Events [12]

The report from T6.1-6.3 integrates milestones MS3-4 and reviews existing EU CS with a focus on EE impacts for the water, energy and food sectors. It will also report suggestions and requirements gathered from the stakeholders in dedicated meetings.

D6.2 : Preliminary report on AI-enhanced Climate Services for extreme impacts [33]

The report integrates milestone MS15 and illustrates the preliminary analysis of AI-enhanced CS for European EE impacts for the water, energy, and food sectors.

D6.3 : AI-enhanced Climate Services for extreme impacts [44]

The report integrates milestone MS37 and evaluates AI-enhanced CS for European EE impacts for the water, energy, and food sectors.

D6.4 : Policy brief - EU Climate Services [48]

A policy brief from T1.1 integrating milestone MS40, targeting policy-makers at EU level and outlining the potential of AI/ML to enhance EU CS across the WEF Nexus.

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS3	Data provision for EU Climate Services	8 - TCDF	9	This MS verifies the data provision for EU Climate Services as produced by task T6.1. Means of verification: Dataset available in the internal project repository
MS4	New impact modelling chains and product derivation methods set-up	13 - JLU	10	This MS is a report about new impact modelling chains and product derivation methods produced by task T6.3. Means of verification: Internal report uploaded to the internal project repository
MS15	Catalogue of water, energy and food related European events, impact indicators and descriptors	5 - SMHI	18	This MS is a report about water, energy and food related European events, impact indicators and descriptors produced by tasks T6.1-6.2-6.3, which will contribute to Deliverable D6.2. Means of verification: Internal report uploaded to the internal project repository
MS37	Datasets of AI-enhanced water, energy and food related Climate Services delivered to WP8	7 - E3M	38	This MS is a report about AI-enhanced water, energy and food related Climate Services produced in tasks T6.1-6.2-6.3, which will contribute to Deliverable D6.3. Means of verification: Internal report uploaded to the internal project repository
MS40	AI methodologies for improved understanding of the WEF Nexus over Europe	1 - POLIMI	44	This MS is a report produced in task T6.4 about AI methodologies for improved understanding of the WEF Nexus over Europe from tasks T6.1-6.2-6.3, including a summary of the interactions with the stakeholders and the feedback they provided. This report will contribute to Deliverable D6.4. Means of verification: Internal report uploaded to the internal project repository.

Work package number [9]	WP7	**Lead beneficiary** [10]	10 - IHE
Work package title	AI-enhanced Climate Services to Foster Adaption at the Local Scale		
Start month	1	**End month**	48

Objectives

Objectives
Extreme Events have a major influence on the daily management and strategic planning at the local scale. AI-enhanced CS have the potential to support local decision-making and adaption design to better cope with increasingly frequent EE. This WP aims at using the AI-enhanced Climate Science of EE from WP3-5 to improve existing or develop new CS to inform decision-making and disaster risk management, and improve climate adaptation options at the local scale. AI-enhanced S2S forecasts and climate change projections will be used as input to existing impact models (hydrology, energy, agricultural production, decision-making). This will foster the development of tailored and sector specific CS and allow assessing their potential added value with respect to existing products. AI-enhanced CS will be developed and assessed in four case studies representing three different Climate Change Hotspots: semiarid regions, river deltas, and snow-dependent river basins. While issues, EE, impacted sectors and adaption measure change across the case studies, a common procedural approach will be adopted consisting of the following steps:
• Providing user-inspired variables, indices and historical case studies of EE to WP3-5 to be explored for AI-enhanced detection, causation, attribution and prediction.
• Establishing benchmark forecast/projection products and correspondingly CS to be used as comparison for AI-enhanced CS.
• Receiving datasets (original and AI-enhanced) from WP3-5 as input to impact models and use case decision-making. Where applicable, outputs from EU and global impact models of WP6 will be incorporated.
• Prototype development of AI-enhanced CS to demonstrate the added value to case study users, facilitating their input, benchmarking, feedback and iteration (soft co-design).
• Assessment of (potential) enhanced adaptation with AI-enhanced CS.

Description of work and role of partners

WP7 - AI-enhanced Climate Services to Foster Adaption at the Local Scale [Months: 1-48]
IHE, POLIMI, CMCC, SMHI, HKV, TCDF, ECMWF, JLU, UCM
Task 7.1: Existing Climate Services and user-identified variables and indicators for Extreme Events [months 1-11] – IHE, POLIMI, UCM, HKV, TCDF, ECMWF
Existing CS in the different Climate Change Hotspots will be surveyed and need for enhancements will be further analysed in collaboration with local stakeholders and decision-makers (see letters of endorsement). Local expertise is key to a deep understanding of how the different EE are recognized and defined in their area and what the impact of these extremes is on the ground. This sometimes extends to knowledge on (early) indications (e.g. environmental variables) of EE. This task aims at assessing this local user knowledge and feeding it as additional input to design user tailored CS. This task will provide user requirement for the CS to be further developed and evaluated in the following tasks. The outcomes of this task will be reported in Deliverables D7.1.

Task 7.2: Semiarid Climate Change Hotspots [months M1-48] – UCM, POLIMI, IHE, TCDF, CMCC, SMHI
This task will develop and demonstrate AI-enhanced CS for semiarid Climate Change Hotspots. Two transboundary study areas will be considered in EU and Africa, the Zambezi Watercourse and the Douro river basin. Different AI-enhanced products will be comparatively analysed in the two case studies with respect to the benchmarks established in T7.5 with a focus on their incremental value in information decision-making and adaption. For the Zambezi Watercourse, AI-enhanced S2S forecasts of tropical cyclones will support the design of a warning system to enhance flood preparedness in the region. Moreover, AI- enhanced S2S hydroclimatic forecasts of drought indices will be used for informing the multipurpose re-operation of a large network of dams and irrigation diversions and will be assessed across all the dimensions of the WEF nexus, focusing on the potential for ZAMCOM (Zambezi River Commission) of mitigating existing conflicts between these competing sectors when confronted with extreme droughts. AI-enhanced climate projections will also be used to condition hydropower and agricultural capacity expansion design and assess its sustainability and adaptability. Similar CS will be demonstrated on the Douro river basin to support the local River Basin Authority in deciding a balance annual water allocation among users. Here the focus will be in the tradeoff between agriculture and ecosystem integrity. To contrast increasingly frequent and more impacting extreme droughts, dynamic

restriction to established environmental flows will be tested as potential adaptation measures. The outcomes of this task will be reported in Deliverables D7.2-7.3.

Task 7.3: Delta Climate Change Hotspot [months 1-48] – HKV, IHE, TCDF, SMHI
This task will develop and demonstrate AI-enhanced Climate Services for delta Climate Change Hotspot. The Rhine Delta in the Netherlands will be used as case study, considering both flood and drought risks. AI-enhanced S2S climatic forecasts will be applied as forcing to hydrological models to predict future surface water, soil moisture, and groundwater availability for the Rijnland and Rhine-and-IJssel water systems. The added value of these AI-enhanced CS in supporting local water authorities in managing surface water allocation and groundwater abstraction during extreme droughts will be assessed. In addition, AI-enhanced climate projections for extra-tropical transition of cyclones will be combined with the outputs of T6.1 to study potential future impact on flood risk in the Netherlands. Information on trends in timing, duration, season and dominant wind direction, will be used in combination with hydraulic impact models to assess what that means for flood risk as these questions are crucial for Dutch authorities for long term delta management. The outcomes of this task will be reported in Deliverables D7.2-7.3.

Task 7.4: Snow Climate Change Hotspot [months M1-48] – POLIMI, SMHI, CMCC, TCDF, JLU
This task will develop and demonstrate AI-enhanced CS for snow Climate Change Hotspots. The Lake Como basin in Italy will be adopted as a case study. The system is facing increasingly frequent and prolonged droughts that are exacerbating the conflict among its multiple stakeholders (citizens, farmers, hydropower companies, and important ecosystem services). AI-enhanced S2S hydroclimatic forecasts will be developed to inform the operation of the lake during extreme drought events in order to better balance flood risk control, agricultural water supply and other water uses. Moreover, S2S forecasts of heatwaves and warm nights will be used to support operators in facing possible detrimental impacts on crop yield, while AI-enhanced climate projections will be used to assess alternative climate adaptation strategies, including crop change, water use licensing, and mobile flood protection systems. Lastly, AI-enhanced compound events detection will be used to better predict the consequences of lower snow accumulation combined with cold and dry springs that impact on the water availability for the key socio-economic sectors. The outcomes of this task will be reported in Deliverables D7.2-7.3.

Task7.5: AI-enhanced Climate Services versus benchmark [months 37-48] – IHE, POLIMI, UCM, HKV, TCDF
This task will comparatively analyse established benchmarks and AI-enhanced products across the different Climate Change Hotspots to provide a concluding report on the potential improved climate adaptation and disaster risk management derived from the AI-enhanced CS. The analysis will consider different angles: per case study, impacted sector combinations, and category of EE. The outcomes of this task will be reported in Deliverable D7.4.

Participation per Partner

Partner number and short name	WP7 effort
1 - POLIMI	29.00
2 - CMCC	6.00
5 - SMHI	13.00
6 - HKV	3.00
8 - TCDF	6.00
10 - IHE	32.00
11 - ECMWF	1.00
13 - JLU	2.00
15 - UCM	16.00
Total	108.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D7.1	Local Climate Services	10 - IHE	Report	Public	10
D7.2	Preliminary AI-enhanced Climate Services for local decision-making	10 - IHE	Report	Public	34
D7.3	AI-enhanced Climate Services for local decision-making	1 - POLIMI	Report	Public	46
D7.4	Policy brief - Local Climate Services	10 - IHE	Other	Public	48

Description of deliverables

The WP will produce four deliverables. The first will provide an overview of existing CS in the different climate hotspots and identify space for improvements of existing services or for new services. The second and the third will illustrate the new AI enhanced services generated by and assessed in CLINT. The last deliverable is a policy brief to inform the climate hotspots stakeholders, EU policy makers, and the public about the WP main findings.

D7.1 : Local Climate Services [10]

Report from T7.1 integrating milestone MS2 and reporting the needs, as suggested by the stakeholders in dedicated meeting, for local CS in the different Climate Change Hotspots and the specifications of existing services, formulating any user-inspired EE variables and indices as input to WP3-5, and formulating the impact indicators for quantifying the value of AI-enhanced CS.

D7.2 : Preliminary AI-enhanced Climate Services for local decision-making [34]

Report from T7.2-4 integrating milestones MS12-14 and describing the preliminary analysis of the value of AI-enhanced CS in the different Climate Change Hotspots for different EE categories.

D7.3 : AI-enhanced Climate Services for local decision-making [46]

Report from T7.2-4 integrating milestones MS38-39 and MS41 and assessing the value of AI-enhanced CS in the different Climate Change Hotspots for different EE categories.

D7.4 : Policy brief - Local Climate Services [48]

A policy brief from T7.5 integrating milestone MS42, targeting local policy-makers and outlining the potential of ML to enhance local CS supporting climate adaptation and disaster risk management.

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS2	Data provision for local Climate Services	8 - TCDF	8	This MS verifies the provision of local Climate Services and is produced by task T7.1. Means of verification: Dataset available in the internal project repository
MS12	Benchmark Climate Services and local use case established for delta hotspots	10 - IHE	14	This MS is a report about benchmark Climate Services at the local scale produced

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
				by task T7.3, which will contribute to Deliverable D7.2. Means of verification: Internal report uploaded to the internal project repository
MS13	Benchmark Climate Services and local use case established for snow hotspots	1 - POLIMI	14	This MS is a report about benchmark Climate Services at the local scale produced by task T7.4, which will contribute to Deliverable D7.2. Means of verification: Internal report uploaded to the internal project repository
MS14	Benchmark Climate Services and local use case established for semiarid hotspots	15 - UCM	16	This MS is a report about benchmark Climate Services at the local scale produced by task T7.2, which will contribute to Deliverable D7.2. Means of verification: Internal report uploaded to the internal project repository.
MS38	AI enhanced Climate Services developed for delta hotspots	6 - HKV	40	This MS is a report about AI-enhanced Climate Services for delta hotspots produced in task T7.3, which will contribute to Deliverable D7.3. Means of verification: Internal report uploaded to the internal project repository
MS39	AI enhanced Climate Services developed for snow hotspots	1 - POLIMI	40	This MS is a report about AI-enhanced Climate Services for snow hotspots produced in task T7.4, which will contribute to Deliverable D7.3. Means of verification: Internal report uploaded to the internal project repository
MS41	AI enhanced Climate Services developed for semiarid hotspots	1 - POLIMI	44	This MS is a report about AI-enhanced Climate Services for semiarid hotspots produced in task T7.2, which will contribute to Deliverable D7.3. Means of verification: Internal report uploaded to the internal project repository
MS42	AI methodologies for local Climate Services	1 - POLIMI	45	This MS is a report about AI methodologies for improving local Climate Services produced in task

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
				T7.5, including a summary of the interactions with the stakeholders and the feedback they provided. This report will contribute to Deliverable D7.4. Means of verification: Internal report uploaded to the internal project repository

Work package number [9]	WP8	Lead beneficiary [10]	14 - OGC
Work package title	Climate Services Information Systems		
Start month	1	End month	48

Objectives

This WP can be seen as improving science to improve CS streams. It will transfer selected scientific methods of the Climate Intelligence (WP2), AI-enhanced Climate Science (WP3-5) and AI-enhanced CS (WP6-7) into CSIS. This will be pursued by developing appropriate WPS respecting the standards of the OGC, which ensures a deployment in the CDS for C3S data production as well as similar EU CS IT infrastructures like EOSC or Wekeo. This WP aims furthermore to demonstrate options for improved CS by generating EE climate information on demand.

Description of work and role of partners

WP8 - Climate Services Information Systems [Months: 1-48]
OGC, POLIMI, CMCC, SMHI, TCDF, DKRZ, ECMWF, UAH, JLU
Task 8.1 Coordination and Guidelines [months 1-48] – OGC, DKRZ, POLIMI, JLU, UAH
This task coordinates the common needs of centralised data (T8.2) and open source code development (T8.3) as well as the co-development from scientific ML-code into CSIS software compartments (T8.4), and provides coordination with WP2-7, development and agreements of coding styles, code of conduct, tutorials, etc. Supporting material will be created to enable and ensure the usability of the technical services since server-side technology is still a new data treatment method. To advance CS, this task is focusing on coordination and guidelines for:
• Organisation of coding sprints and monthly video conferences;
• Developer communication (e.g. on Gitter);
• WPS architecture design and software coding style;
• CS Information Systems architecture in line with FAIR principles;
• Data Management Plan.
The outcomes of this task will be reported in Deliverables D8.1-8.3-8.6-8.8.

Task 8.2 Climate data repository and management [months 4-48] - DKRZ, POLIMI, SMHI, TCDF
This task coordinates work related to the implementation of data management plan defined in T8.1 and establishes a data repository collecting and managing core input and output data in support of WP2-8. Beside supporting the whole project by coordinated provisioning and sharing of data, this task will ensure the sustainable storage and management of core data collections according to FAIR data principles. This is enabled by a close collaboration with a certified long-term archive managed at DKRZ. The identification of core data collections to be managed in centralized repositories is done in close collaboration with a continuous maintenance of the data management plan, which will be ensured by the adoption of the RDMO tool hosted at DKRZ. Input Data will be provided in each individual WP (WP3-7) as downscaled proprietary data by TCDF and will be organized, stored, and managed in this WP. Output data collections will be identified and collected in close collaboration with the individual work packages in WP3-7 and may be used for example as input to Copernicus Services like CEMS. The outcomes of this task will be reported in Deliverables D8.2-8.4.

Task 8.3 CS Information Systems Backend [months 7-48] – OGC, DKRZ, ECMWF
The goal of this task is to develop the software architecture in which scientific ML code can be implemented (T8.4). The architecture will be tailored and deployable on C3S/CDS, other EU CSIS like EOSC or Wekeo as well as operational for SMEs. T8.3 is focusing on appropriate backend design, OGC-interoperability and optimisation of performance. The task will administer a DEMO processing service to show the new developed CSIS components from T8.4 with selected input data from T8.2. An open web standard conform web mapping service for direct data visualisation will be provided as well. The task will cover:
• Research for backend optimization;
• Setup C3S compatible ML-code WPS skeletons with 'birdhouse-cookiecutter';
• Web Mapping Service (e.g., pavics);
• Code repository management.
The outcomes of this task will be reported in Deliverable D8.5.

Task 8.4 WPS prototypes for C3S [months 13-48] – OGC, DKRZ, ECMWF, CMCC, POLIMI
This task will develop functional CSIS components by transferring selected ML code into the WPS skeletons provided by T8.3. This activity will be a co-development by AI experts in WP2, Climate Scientists in WP3-5 and data science

experts (DKRZ) to ensure high level technical functionality as well as scientific validation. All components are designed for extension. WPS will be written in the programming language Python, and will include i) conda packages for code dependencies; ii) software documentation with Sphinx (incl. automatic Application Programming Interface (API) documentation); iii) training material for the usage of the service. The outcomes of this task will be reported in Deliverable D8.7. The task is organized into two subtasks:

Subtask 8.4.1: WPS processes to fill missing values
The WPS focusing on the spatial infilling of missing values will be the first service by WP8. The task will have a technical interface to read NetCDF files, a pointer towards the trained neural network on near-surface air temperature anomalies, which fills in the gaps on the given datasets into a NetCDF and a quick-look plot. Research within this task includes a feasibility study on the possibility of also training the neural network on a given training, validation and test dataset. The technology will be further developed in WP2 and analysed and evaluated especially regarding trends on extremes in WP5 on a later stage.

Subtask 8.4.2 WPS for AI-enhanced Climate Science
The WPS processes focusing on EE will be based on the ML code developed in T2.1 tailored for the scientific problems formulated in WP3-5. In this subtask, ML-methods to detect and analyse different types of EE will be transformed into WPS processes, with a focus on three processes:
• Processes for tropical cyclones genesis index - The tropical cyclones genesis index aims to improve the early detection of risks for tropical cyclone formation. The index will be based on atmospheric 3-dimensional fields and ocean surface data.
• Processes for heatwaves index - A spatio-temporal heatwave index will be developed to identify and characterise the severity of warm temperature extremes at different spatial and temporal scales. This process will be focused on the detection of the EE heatwave index from the input data in a specific domain.
• Processes for projections of heatwaves - This service will be focused on future changes of heatwaves, as provided by WP5, as an example of AI-enhanced Climate Science integrating efforts across WP3-5. The developed service will allow the user to get different storylines of plausible future changes in European heatwaves and their associated large-scale fields, including the best and the worst-case outcomes for different levels of global warming.

Participation per Partner

Partner number and short name	WP8 effort
1 - POLIMI	5.00
2 - CMCC	5.00
5 - SMHI	4.00
8 - TCDF	2.00
9 - DKRZ	26.00
11 - ECMWF	3.00
12 - UAH	1.00
13 - JLU	1.00
14 - OGC	17.00
Total	64.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D8.1	Data Management Plan	1 - POLIMI	ORDP: Open Research Data Pilot	Public	6
D8.2	Preliminary operational data repository	9 - DKRZ	Report	Confidential, only for members of the consortium (including the Commission Services)	16
D8.3	Data Management Plan - first update	14 - OGC	Report	Confidential, only for members of the consortium (including the Commission Services)	18
D8.4	Central data repository	9 - DKRZ	Report	Public	24
D8.5	Climate Services Information Systems architecture	9 - DKRZ	Other	Public	36
D8.6	Data Management Plan - second update	1 - POLIMI	Report	Confidential, only for members of the consortium (including the Commission Services)	36
D8.7	Extreme Events ML in Climate Services Information Systems	14 - OGC	Report	Public	47
D8.8	Final Data Management Plan	9 - DKRZ	ORDP: Open Research Data Pilot	Public	48

Description of deliverables

The WP will deliver seven products. Five (D8.1-4 and D8.6) are related to data organization and management both in terms of policy and tools to process and archive data and will also report on the progress on data management The other two reports (D8.5 and D8.7) illustrate the backend related software architecture and provide a user guide for the CLINT Climate Services Information Systems.

D8.1 : Data Management Plan [6]

Report from T8.1 describing the policy concerning the acquisition, storage and classification and management and distribution of project data. The report will include procedures for data collection, storage, protection, retention and destruction.

D8.2 : Preliminary operational data repository [16]

Preliminary report from T8.2 integrating milestone MS1 and describing the setup of the central data repositories.

D8.3 : Data Management Plan - first update [18]

This deliverable from T8.1 includes an updated version of deliverable D8.1 Data Management Plan.

D8.4 : Central data repository [24]

Report from T8.2 updating deliverable D8.2 and describing the setup and maintenance workflow of the central data repositories

D8.5 : Climate Services Information Systems architecture [36]

Detailed description of backend related software architecture. The report from T8.3 integrates milestone MS21 and will include the descriptions new developed and already available components to establish CSIS services providing ML codes as processes. The report will also include the appropriate code repositories.

D8.6 : Data Management Plan - second update [36]

This deliverable from T8.1 includes an updated version of deliverable D8.3 Data Management Plan - first update.

D8.7 : Extreme Events ML in Climate Services Information Systems [47]

Report from T8.4 integrating milestone MS28 and providing a detailed description of frontend related technical usage, handling and performance of functions of the developed WPS processes. It can be seen as the overall user guide to assess EE with ML via CSIS.

D8.8 : Final Data Management Plan [48]

This deliverable from T8.1 includes the final Data Management Plan with final changes/agreements on project data.

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS1	Data repository designed and ready for input data	9 - DKRZ	6	This MS verifies the design of the data repository produced by task T8.2. Means of verification: Data repository online
MS21	EE CS Information Systems architecture with AI	9 - DKRZ	24	This MS is a report about the EE CS Information Systems architecture produced in task T8.3, which will contribute to Deliverable D8.5. Means of verification: Internal report uploaded to the internal project repository
MS28	EE CS Information Systems DEMO containing all WPS components	2 - CMCC	36	This MS is a report about Climate Services Information Systems DEMO produced in task T8.4, which will contribute to Deliverable D8.7. Means of verification: Internal report uploaded to the internal project repository

Work package number [9]	WP9	**Lead beneficiary** [10]	8 - TCDF
Work package title	Exploitation, Dissemination, and Communication		
Start month	1	**End month**	48

Objectives

The aim of this WP is to create and manage communication, scientific dissemination, outreach to policy-makers, and exploitation of the project outcomes by public and private institutions. To this end, the work in this WP will involve the set-up of communication, dissemination and exploitation material specifically tailored to the interests of a diverse audience including policy-makers, expert and practitioners including the private sector, the scientific community, the general public and civil society. The activities of this WP will target three main objectives:

• Develop a public website and communication platform to facilitate the dialogue between project partners and end-users

• Define communication and dissemination activities targeting specific key audiences as well as national and international research initiatives (e.g. IAHS Panta Rhei or WMO High Impact Weather)

• Development of operational prototypes of a commercial CS based on project results for exploitation after the project.

Description of work and role of partners

WP9 - Exploitation, Dissemination, and Communication [Months: 1-48]
TCDF, POLIMI, CMCC, HZG, CSIC, SMHI, HKV, E3M, DKRZ, IHE, ECMWF, UAH, JLU, OGC, UCM
Task 9.1: Communication and dissemination strategy [months 1-12] – POLIMI, CMCC, SMHI
A communication and dissemination plan will provide a description of the specific activities and schedule for outreach and the dissemination of the results and knowledge generated in the project for the different audiences. The communication plan will define various actions and communication channels considering the needs of and differences between different target audiences. The outcomes of this task will be reported in Deliverable D9.2.

Task 9.2: Dissemination Material [months 1-48] – POLIMI, CMCC
This task will produce promotional material for project dissemination. A progressively enriched information package will be made available reflecting the brand and objectives and expected results, including project leaflets and factsheet, a project website to provide all necessary information about the project (goals, partners, activities, deliverables, etc.), periodic newsletters, press releases, and scientific papers. Project development and results will also be regularly disseminated through dedicated social media channels, such as Twitter and/or LinkedIn. The outcomes of this task will be reported in Deliverable D9.1-9.2.

T9.3: Direct outreach activities [months 1-48] – CMCC, POLIMI, HZG, CSIC, SMHI, IHE, DKRZ, JLU, ECMWF, HKV, E3M, TCDF, OGC
This task organizes and manages the main dissemination activities that will be organized during the project lifetime. Each year the dissemination and exploitation plan will identify a set of target audience that will be specifically approached. Dissemination events will be likely organized in the occurrence of specific events at the national and international level. Dissemination among policy-makers and practitioners will also be supported by attendance and participation at corresponding professional, expert group and committee meetings and other events. Exchange of information and experiences with related European projects will be supported through participation in H2020 consultation meetings and networking events. Finally, know-how transfer will be organized through a series of webinars and/or an online summer school. The outcomes of this task will be reported in Deliverables D9.4, D9.6, D9.10.

T9.4: Exploitation strategy [months 1-48] – TCDF, ALL
This task organizes the exploitation strategy of the CLINT project results after the end of the project. A particular focus will be on the definition of individual and joint exploitation options, including the potential uptake of the CLINT outcomes by the Copernicus programme as well as by the SME partners and potentially other public and private entities. The outcomes of this task will be reported in Deliverables D9.3, D9.5, D9.7.

T9.5 AI-enhanced operational prototypes [months 13-48] - TCDF
The goal of this task is to implement selected project developments into production on cloud resources to support product development for commercial exploitation after the project. The services will be tested for heatwaves and extreme droughts detection and attribution and provide scientific and technical feedback to WP3-5 and WP8 respectively. Two production modes will be set up as operating services prototypes on a cloud environment: one based on S2S forecast

and one based on climate projections using a coherent and seamless data production scheme at the global level (ERA5 based resolution).
Those production prototypes will support WP6 and WP7 data needs with production data and will set the basis of two AI-enhanced CS that will run under production mode during the last year of the project and then be exploited as commercial services after the project. The outlooks will be freely available during the duration of the project. The outcomes of this task will be reported in Deliverables D9.8-9.9.

Subtask 9.5.1: AI-enhanced S2S forecast of heatwaves/droughts and ex-post attribution service demonstrator
The goal of this subtask is to set up and run in a production mode a prototype as a demonstrator of a S2S forecasting service of detection with an ex post attribution final assessment. The technical implementation will be done in two manners, first testing code directly developed by the scientist from WP2-5, second testing the corresponding APIs/WPS encapsulating the same code developed in WP8. This will allow code benchmarking and address optimisation issues appearing under production mode as a feedback to WP8. It will also allow part of WP6 and WP7 services to operate under production mode. The operational monthly forecast from ECMWF and operational S2S forecast from the C3S of the CDS will be used as forecast, and near real-time ERA5 reanalysis will be used for rapid attribution diagnostics. This task includes a skill analysis of the forecast products for a few historical European EE events over the last 20 years.

Subtask 9.5.1: AI-enhanced evaluation of future extreme droughts service
The goal of this subtask is to develop a series of local services on drought indices based on the use cases developed in WP7. The aim is to be able to replicate the evaluation of weather variables and indices components (e.g. only atmospheric components) as a service that can be provided for local climate adaptation to professionals from other locations/hotspots around the world. As in the previous subtask, it will test both scientific code and APIs/WPS and provide feedback to WP8 and interact with WP7 for service and product specifications.

Participation per Partner

Partner number and short name	WP9 effort
1 - POLIMI	9.00
2 - CMCC	8.00
3 - HZG	3.00
4 - CSIC	3.00
5 - SMHI	3.00
6 - HKV	1.00
7 - E3M	1.00
8 - TCDF	30.00
9 - DKRZ	1.00
10 - IHE	4.00
11 - ECMWF	1.00
12 - UAH	1.00
13 - JLU	2.00
14 - OGC	2.00
15 - UCM	1.00
Total	70.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D9.1	CLINT website, visual identity and logo	1 - POLIMI	Websites, patents filing, etc.	Public	3
D9.2	Communication and Dissemination plan	1 - POLIMI	Report	Public	6
D9.3	Preliminary exploitation strategy	8 - TCDF	Report	Confidential, only for members of the consortium (including the Commission Services)	6
D9.4	Communication and Dissemination plan - first update	2 - CMCC	Report	Public	18
D9.5	Intermediate exploitation strategy	8 - TCDF	Report	Confidential, only for members of the consortium (including the Commission Services)	24
D9.6	Communication and Dissemination plan - second update	2 - CMCC	Report	Public	36
D9.7	Final exploitation strategy	8 - TCDF	Report	Confidential, only for members of the consortium (including the Commission Services)	46
D9.8	AI-enhanced operational prototypes	8 - TCDF	Report	Public	48
D9.9	AI-enhanced S2S forecast demonstrator	8 - TCDF	Demonstrator	Public	48
D9.10	Final Communication and Dissemination report	2 - CMCC	Report	Public	48

Description of deliverables

The WP will deliver 9 products describing all the tools and support for communication and dissemination, including website, social media accounts, as well as the communication/dissemination plan and reports, and the exploitation strategy. It will also releases AI-enhanced operational prototypes and AI-enhanced S2S forecast demonstrator.

D9.1 : CLINT website, visual identity and logo [3]

Initial package of the communication material, including the project logo, website, social media. This dissemination material from T9.2 will be continuously updated throughout the project.

D9.2 : Communication and Dissemination plan [6]

Report from T9.1-9.2 describing the strategies that will be used to obtain the objectives of this WP. The plan will include a communication requirements analysis, identification of stakeholders and target audiences, and will outline dissemination activities and channels to be used and will display time management features for their implementation.

D9.3 : Preliminary exploitation strategy [6]

Work package number [9]	WP10	**Lead beneficiary** [10]	1 - POLIMI
Work package title	Ethics requirements		
Start month	1	**End month**	48

Objectives

The objective is to ensure compliance with the 'ethics requirements' set out in this work package.

Description of work and role of partners

WP10 - Ethics requirements [Months: 1-48]
POLIMI
This work package sets out the 'ethics requirements' that the project must comply with.

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D10.1	POPD - Requirement No. 1	1 - POLIMI	Ethics	Confidential, only for members of the consortium (including the Commission Services)	4
D10.2	NEC - Requirement No. 2	1 - POLIMI	Ethics	Confidential, only for members of the consortium (including the Commission Services)	4

Description of deliverables

The 'ethics requirements' that the project must comply with are included as deliverables in this work package.

D10.1 : POPD - Requirement No. 1 [4]

A description of the technical and organisational measures that will be implemented to safeguard the rights and freedoms of the data subjects/research participants must be submitted as a deliverable.

D10.2 : NEC - Requirement No. 2 [4]

Detailed information to demonstrate that fair benefit-sharing arrangements with stakeholders from low and lower-middle income countries are ensured must be submitted as a deliverable. Copies of import/export authorisations, as required by national/EU legislation must be kept on file.

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification

1.3.4. WT4 List of milestones

Milestone number[18]	Milestone title	WP number[9]	Lead beneficiary	Due Date (in months)[17]	Means of verification
MS1	Data repository designed and ready for input data	WP8	9 - DKRZ	6	This MS verifies the design of the data repository produced by task T8.2. Means of verification: Data repository online
MS2	Data provision for local Climate Services	WP7	8 - TCDF	8	This MS verifies the provision of local Climate Services and is produced by task T7.1. Means of verification: Dataset available in the internal project repository
MS3	Data provision for EU Climate Services	WP6	8 - TCDF	9	This MS verifies the data provision for EU Climate Services as produced by task T6.1. Means of verification: Dataset available in the internal project repository
MS4	New impact modelling chains and product derivation methods set-up	WP6	13 - JLU	10	This MS is a report about new impact modelling chains and product derivation methods produced by task T6.3. Means of verification: Internal report uploaded to the internal project repository
MS5	Climate dataset provision for EE detection analysis	WP3	8 - TCDF	12	This MS verifies the provision of climate dataset for EE detection produced in task T3.2. Means of verification: Dataset available in the internal project repository
MS6	Indices for tropical cyclones	WP3	2 - CMCC	14	This MS is a report about indices for tropical cyclones produced in task T3.1, which will contribute to Deliverable D3.1. Means of verification: Internal report uploaded to the internal project repository
MS7	Datasets and candidate drivers for tropical cyclones	WP3	11 - ECMWF	14	This MS is a report about datasets and drivers for tropical cyclones produced in task T3.1, which will contribute to Deliverable D3.1. Means of verification: Internal report uploaded to the internal project repository

Milestone number[18]	Milestone title	WP number[9]	Lead beneficiary	Due Date (in months)[17]	Means of verification
MS8	Datasets and candidate drivers for extratropical transitions	WP3	2 - CMCC	14	This MS is a report about dataset and drivers for extratropical transitions produced in task T3.1, which will contribute to Deliverable D3.1. Means of verification: Internal report uploaded to the internal project repository
MS9	Datasets and candidate drivers for heatwaves and tropical nights	WP3	2 - CMCC	14	This MS is a report about datasets and drivers for heatwaves and tropical nights produced in task T3.2, which will contribute to Deliverable D3.1. Means of verification: Internal report uploaded to the internal project repository
MS10	Datasets and candidate drivers for extreme droughts	WP3	1 - POLIMI	14	This MS is a report about datasets and drivers for extreme droughts produced in tast T3.3, which will contribute to Deliverable D3.1. Means of verification: Internal report uploaded to the internal project repository
MS11	Datasets and candidate drivers for compound events and concurrent extremes	WP3	13 - JLU	14	This MS is a report about datasets and drivers for compound events and concurrent extremes produced in task T3.4, which will contribute to Deliverable D3.1. Means of verification: Internal report uploaded to the internal project repository
MS12	Benchmark Climate Services and local use case established for delta hotspots	WP7	10 - IHE	14	This MS is a report about benchmark Climate Services at the local scale produced by task T7.3, which will contribute to Deliverable D7.2. Means of verification: Internal report uploaded to the internal project repository
MS13	Benchmark Climate Services and local use case established for snow hotspots	WP7	1 - POLIMI	14	This MS is a report about benchmark Climate Services at the local scale produced by task T7.4, which will contribute to Deliverable D7.2. Means of verification: Internal report uploaded to the internal project repository
MS14	Benchmark Climate Services and local use	WP7	15 - UCM	16	This MS is a report about benchmark Climate Services

Milestone number[18]	Milestone title	WP number[9]	Lead beneficiary	Due Date (in months)[17]	Means of verification
	case established for semiarid hotspots				at the local scale produced by task T7.2, which will contribute to Deliverable D7.2. Means of verification: Internal report uploaded to the internal project repository.
MS15	Catalogue of water, energy and food related European events, impact indicators and descriptors	WP6	5 - SMHI	18	This MS is a report about water, energy and food related European events, impact indicators and descriptors produced by tasks T6.1-6.2-6.3, which will contribute to Deliverable D6.2. Means of verification: Internal report uploaded to the internal project repository
MS16	Attribution framework for different types of EE defined	WP5	4 - CSIC	16	This MS is a report about the attribution framework produced in task T5.1, which will contribute to Deliverable D5.1. Means of verification: Internal report uploaded to the internal project repository
MS17	First prototype of algorithms for reconstructions of missing EE values	WP2	9 - DKRZ	22	This MS is a report about algorithms for reconstructions of missing EE values produced in task T2.5, which will contribute to Deliverable D2.2. Means of verification: Internal report uploaded to the internal project repository
MS18	Candidate causal relationships identified	WP4	3 - HZG	22	This MS is a report about the identification of causal relationships produced in task T4.1, which will contribute to Deliverable D4.1. Means of verification: Internal report uploaded to the internal project repository
MS19	First prototype of algorithms for EE detection	WP2	1 - POLIMI	24	This MS is a report about algorithms for EE detection produced in task T2.1, which will contribute to Deliverable D2.3. Means of verification: Internal report uploaded to the internal project repository
MS20	First prototype of algorithms for EE attribution	WP2	12 - UAH	24	This MS is a report about algorithms for EE attribution produced in task T2.3, which will contribute to Deliverable D2.3. Means of verification:

Milestone number[18]	Milestone title	WP number[9]	Lead beneficiary	Due Date (in months)[17]	Means of verification
					Internal report uploaded to the internal project repository
MS21	EE CS Information Systems architecture with AI	WP8	9 - DKRZ	24	This MS is a report about the EE CS Information Systems architecture produced in task T8.3, which will contribute to Deliverable D8.5. Means of verification: Internal report uploaded to the internal project repository
MS22	First prototype of algorithms for EE forecasting	WP2	10 - IHE	26	This MS is a report about algorithms for EE forecasting produced in task T2.4, which will contribute to Deliverable D2.2. Means of verification: Internal report uploaded to the internal project repository
MS23	First prototype of algorithms for EE causation	WP2	1 - POLIMI	28	This MS is a report about algorithms for EE causation produced in task T2.2, which will contribute to Deliverable D2.3. Means of verification: Internal report uploaded to the internal project repository
MS24	Candidate extremes for mutual causality identified	WP4	13 - JLU	28	This MS is a report about the identification of extremes for mutual causality produced in task T4.1, which will contribute to Deliverable D4.1. Means of verification: Internal report uploaded to the internal project repository
MS25	Historical EE selected for attribution studies	WP5	4 - CSIC	28	This MS is a report about the selection of historical EE for attribution studies produced in task T5.1, which will contribute to Deliverable D5.2. Means of verification: Internal report uploaded to the internal project repository
MS26	Trends in EE detected	WP5	9 - DKRZ	32	This MS is a report about trends in EE produced in task T5.2, which will contribute to Deliverable D5.2. Means of verification: Internal report uploaded to the internal project repository
MS27	Storylines of projected changes in each type of EE constructed	WP5	2 - CMCC	34	This MS is a report about projected changes in EE produced in task T5.3, which

Milestone number[18]	Milestone title	WP number[9]	Lead beneficiary	Due Date (in months)[17]	Means of verification
					will contribute to Deliverable D5.2. Means of verification: Internal report uploaded to the internal project repository
MS28	EE CS Information Systems DEMO containing all WPS components	WP8	2 - CMCC	36	This MS is a report about Climate Services Information Systems DEMO produced in task T8.4, which will contribute to Deliverable D8.7. Means of verification: Internal report uploaded to the internal project repository
MS29	First version of the AI-enhanced S2S forecast demonstrator	WP9	8 - TCDF	36	This MS verifies the development of AI-enhanced S2S forecast demonstrator produced in task T9.5, which will contribute to Deliverable D9.8. Means of verification: software released
MS30	AI improved indices for tropical cyclones	WP3	2 - CMCC	38	This MS is a report about AI improved indices for tropical cyclones produced in task T3.1, which will contribute to Deliverable D3.3. Means of verification: Internal report uploaded to the internal project repository
MS31	ML improved detection of tropical cyclones	WP3	11 - ECMWF	38	This MS is a report about improved detection of tropical cyclones produced in task T3.1, which will contribute to Deliverable D3.3. Means of verification: Internal report uploaded to the internal project repository
MS32	ML improved detection of heatwaves and warm nights	WP3	2 - CMCC	38	This MS is a report about improved detection of heatwaves and warm nights produced in task T3.2, which will contribute to Deliverable D3.3. Means of verification: Internal report uploaded to the internal project repository
MS33	ML improved detection of extreme droughts	WP3	1 - POLIMI	38	This MS is a report about improved detection of extreme droughts produced in task T3.3, which will contribute to Deliverable D3.3. Means of verification: Internal report uploaded to the internal project repository

Milestone number[18]	Milestone title	WP number[9]	Lead beneficiary	Due Date (in months)[17]	Means of verification
MS34	ML improved detection of compound events and concurrent extremes	WP3	13 - JLU	38	This MS is a report about improved detection of compound events and concurrent extremes for tropical cyclones produced in task T3.4, which will contribute to Deliverable D3.3. Means of verification: Internal report uploaded to the internal project repository
MS35	Physically validated causal networks for each type of EE	WP4	12 - UAH	38	This MS is a report about EE causal networks produced in task T4.2, which will contribute to Deliverable D4.2. Means of verification: Internal report uploaded to the internal project repository
MS36	Identification of concurrent and physically linked European EE	WP4	13 - JLU	38	This MS is a report about the identification of concurrent and physically linked European EE produced in task T4.2, which will contribute to Deliverable D4.2. Means of verification: Internal report uploaded to the internal project repository
MS37	Datasets of AI-enhanced water, energy and food related Climate Services delivered to WP8	WP6	7 - E3M	38	This MS is a report about AI-enhanced water, energy and food related Climate Services produced in tasks T6.1-6.2-6.3, which will contribute to Deliverable D6.3. Means of verification: Internal report uploaded to the internal project repository
MS38	AI enhanced Climate Services developed for delta hotspots	WP7	6 - HKV	40	This MS is a report about AI-enhanced Climate Services for delta hotspots produced in task T7.3, which will contribute to Deliverable D7.3. Means of verification: Internal report uploaded to the internal project repository
MS39	AI enhanced Climate Services developed for snow hotspots	WP7	1 - POLIMI	40	This MS is a report about AI-enhanced Climate Services for snow hotspots produced in task T7.4, which will contribute to Deliverable D7.3. Means of verification: Internal report uploaded to the internal project repository

Milestone number[18]	Milestone title	WP number[9]	Lead beneficiary	Due Date (in months)[17]	Means of verification
MS40	AI methodologies for improved understanding of the WEF Nexus over Europe	WP6	1 - POLIMI	44	This MS is a report produced in task T6.4 about AI methodologies for improved understanding of the WEF Nexus over Europe from tasks T6.1-6.2-6.3, including a summary of the interactions with the stakeholders and the feedback they provided. This report will contribute to Deliverable D6.4. Means of verification: Internal report uploaded to the internal project repository.
MS41	AI enhanced Climate Services developed for semiarid hotspots	WP7	1 - POLIMI	44	This MS is a report about AI-enhanced Climate Services for semiarid hotspots produced in task T7.2, which will contribute to Deliverable D7.3. Means of verification: Internal report uploaded to the internal project repository
MS42	AI methodologies for local Climate Services	WP7	1 - POLIMI	45	This MS is a report about AI methodologies for improving local Climate Services produced in task T7.5, including a summary of the interactions with the stakeholders and the feedback they provided. This report will contribute to Deliverable D7.4. Means of verification: Internal report uploaded to the internal project repository
MS43	Basic version of the Forecast demonstrator	WP9	8 - TCDF	24	This MS verifies the initial development of AI-enhanced S2S forecast demonstrator produced in task T9.5, which will contribute to Deliverable D9.8. Means of verification: software released
MS44	Methods and software to be implemented in the AI-Enhanced demonstrators	WP9	8 - TCDF	31	This MS is a report about the code developed in WP 3-4-5-8 which will be used in Task 9.5 for the development of the AI-enhanced forecast demonstrator, and will contribute to Deliverable D9.7. Means of verification: Internal report uploaded to the internal project repository

1. Excellence

Climate Services (CS) are an essential component of adaptation and mitigation strategies as well as disaster risk management, today and under future climate conditions[1], when Extreme Events (EE) are expected to increase in both frequency and intensity in many regions of the world[2]. Future changes of EE are, however, regionally more complex than that expected from thermodynamic changes alone[3], limiting the implementation of effective local and regional adaptation strategies, and the value of information provided to meet the Paris Agreement and Sustainable Development Goals (e.g. climate action, clean water and sanitation, sustainable cities and communities, life on land, affordable and clean energy). At the same time, CS can benefit from the unprecedented availability of data, in particular from the Copernicus Climate Change Service (C3S), to strengthen our understanding of the climate system and EE, as well as of the socio-economic sectors impacted by EE. Critically, recent advances in Artificial Intelligence (AI)[4] and Machine Learning (ML)[5] offer a unique opportunity to exploit the full potential of these data with the aim of providing easily accessible, timely, and decision-relevant information to policy-makers and end-users. This has inspired over the last decade a growing number of collaborations between climate scientists and ML experts[6], which may also open the path to new sustainable development strategies across different socio-economic sectors that need timely and effective climate actions[7,8].

The **main objective** of CLINT is the development of an **Artificial Intelligence framework (Climate Intelligence)** composed of Machine Learning techniques and algorithms to **process big climate datasets** for improving **Climate Science** in the **detection, causation and attribution of Extreme Events**, including tropical cyclones, heatwaves and warm nights, and extreme droughts, along with compound events and concurrent extremes (see Box 1). The CLINT AI framework will also cover the quantification of the EE impacts on a variety of socio-economic sectors under historical, forecasted and projected climate conditions, and across different spatial scales, from the whole European to the local scale, ultimately developing innovative and sectorial **AI-enhanced Climate Services**. Finally, these services will be operationalized into Web Processing Services, according to most advanced open data and software standards by **Climate Services Information Systems,** and into a **Demonstrator** to facilitate the uptake of project results by public and private entities for research and Climate Services development.

The CLINT AI framework (see cover) will put forward innovative techniques for detection, causation and attribution of EE by applying AI and ML algorithms to big datasets (e.g. Copernicus Climate Data Store, CDS) for: (1) identifying and analysing unforeseen connections and relationships between EE and large-scale climatological fields; (2) inferring and quantifying their causal interdependencies and the underlying physical mechanisms involved in EE, concurrent EE and compound events; (3) generating sub-seasonal to seasonal forecasts (S2S) of EE working with potential lag times between the detected large-scale fields and the associated EE; (4) detecting human fingerprints and quantifying future changes in the

[1] Goddard L. (2016), From science to service, *Science*.

[2] Lehmann et al. (2015), Increased record-breaking precipitation events under global warming, *Climatic Change.*

[3] Shepherd T.G. (2014), Atmospheric circulation as a source of uncertainty in climate change projections, *Nature Geoscience.*

[4] Ghahramani Z. (2015), Probabilistic machine learning and artificial intelligence, *Nature.*

[5] Rolnick et al. (2019), Tackling climate change with machine learning, *arXiv:1906.05433.*

[6] Monteleoni et al. (2013), Climate informatics: accelerating discovering in climate science with machine learning, *Computing in Science & Engineering*

[7] Trenberth et al. (2016), The vital need for a climate information system, *Nature Climate Change.*

[8] Vaughan et al. (2018), Surveying Climate Services: What Can We Learn from a Bird's-Eye View?, *Weather, Climate, and Society.*

causal links between large-scale fields and EE. As a result, the CLINT AI framework will provide a prototype of enhanced CS at the forefront of existing services, such as the those offered by C3S. These AI-enhanced CS will support several EU policies addressing multi-sector interests across the Water-Energy-Food (WEF) Nexus, e.g. the EU Floods Directive, the new Green Deal, the Climate Adaptation Strategy, the Common Agricultural Policy, the Clean Planet for all Communication, and the 2030 Energy and Climate Framework. They will also assist disaster risk reduction policies (e.g. the Sendai Framework) and contribute to the EU AI policy. Moreover, CLINT will assess the value of these CS in informing decision-making at the local scale, supporting early warning systems and adaptation measures in three types of Climate Change Hotspots[9]: semiarid regions, river deltas, and snow-dependent river basins. Finally, CLINT will transfer selected scientific methods into Climate Services Information Systems (CSIS) by developing appropriate Web Processing Services (WPS) to ensure a potential uptake of the project results by Copernicus climate-related services, including C3S and Copernicus Emergency Management Service (CEMS), but also other public and private entities.

BOX 1: CLINT Extreme Events

Tropical Cyclones

Despite tropical cyclones being developed along the tropical belt, their extratropical transition phase in the Atlantic basin is of great interest for European countries due to their role in determining extreme precipitation events over the western coast of Europe[10]. In addition, the poleward and eastward extension of the hurricane genesis area induced by climate warming[11] poses increasing risks of extreme precipitation and flooding to Western Europe. Several European countries do also have important economic interests in areas traditionally affected by tropical cyclones. Different indices have been developed to derive tropical cyclones activity based on large scale fields. For example, Genesis Potential Indices (GPI[12]) have been developed to characterize the cyclones genesis over a basin (and also globally) and Maximum Potential Intensity indices (MPI[13]) have been employed to define the upper bound of tropical cyclone intensity. No consensus has been achieved in the past on the consistency between annual tropical cyclones count based on tracking and the aforementioned GPI indices. This is also true when investigating the annual energy associated to the cyclones and the MPI derived from large scale fields. This disagreement affects the reliability and homogeneity of time series of tropical cyclones counts and intensity, hampering the understanding of their drivers, the accuracy of predictions and the detection and attribution of trends. CLINT will investigate the role of the different index components (large scale fields) for tropical cyclones count to support the ML-based formulation of new and comprehensive indices that better support tropical cyclone detections. Moreover, CLINT will enhance tropical cyclones predictions by identifying through AI key aspects of the 3-dimensional atmospheric structure preceding the genesis of tropical cyclones. Lastly, CLINT will assess the emergent European risks from extreme wind and precipitation, and associated flooding from changes in extra-tropical transition of tropical cyclones induced by climate warming.

Heatwaves and Warm Nights

Heatwaves are severely impacting events for ecosystems, human communities, and key socio-

[9] Szabo et al. (2016), Making SDGs Work for Climate Change Hotspots, *Environment: Science and Policy for Sustainable Development*.

[10] Hickey K. (2011), The Impact of Hurricanes on the Weather of Western Europe, *Recent Hurricane Research–Climate, Dynamics, and Societal Impacts, InTech*

[11] Haarsma et al. (2013), More hurricanes to hit Western Europe due to global warming. *Geophysical Research Letters*

[12] Emanuel K.A., and D.S. Nolan (2004), Tropical cyclones and the global climate system, *In Proceedings of the 26th Conference on Hurricanes and Tropical Meteorology*

[13] Bister, M., and K. Emanuel (2002), Low frequency variability of tropical cyclone potential intensity 1. Interannual to interdecadal variability. *Journal of Geophysical Research*

economic sectors[14]. For example, in agriculture and food production, very hot daytime temperatures have a well-known effect on plants evapotranspiration, leading to water-stress conditions that may compromise yield, even in presence of established irrigation plans[15]; on the other hand, recurrent episodes of elevated night temperatures may favour the proliferation of pests and/or the diffusion of diseases[16]. Likewise, energy demand can be strongly affected by both conditions, since warm nights may prevent the expected night-time demand drop following the daily energy request peak. Moreover, the occurrence of both heatwaves and warm nights is projected to increase sharply even in a mitigated global warming scenario[17]. Large part of the recent literature has focused on quantifying heatwave characteristics based on maximum temperatures[18] or daily mean temperatures[19], using a diversity of complex indices for their intensity, persistence and recurrence. However, these indices are defined at grid point level and do not account for the areal extent, spatial structure and time-evolving patterns of heatwave events, which are highly relevant to assess the affected areas and associated impacts. On the other hand, night-time temperature is likewise a crucial factor in determining heatwave magnitude[20], and its societal impact may be complementary to that of extremely high diurnal temperatures. Processes involved in the occurrence of night- and day-time extreme heat are not necessarily the same[21], since the highest maximum temperature generally occurs under dry air conditions, while the warmest nights are usually characterized by high relative humidity that does not allow heat dispersion and thus air cooling. CLINT will advance the detection of heatwaves and warm nights drivers by combining information from large-scale fields as well as local land surface variables via ML algorithms. This will allow an improved understanding of their multiple causal factors, some of which remain poorly understood (e.g. sea surface temperatures) and the quantification of human influences. Ultimately, CLINT will contribute to AI-tailored CS developments of future changes in heatwaves to better inform local adaptation strategies and policies within the WEF Nexus.

Extreme Droughts

A drought is a slowly developing natural phenomenon that can occur in all climatic zones and can be defined as a temporary but significant decrease in water availability[22]. Although drought management is largely studied in the literature[23], traditional drought indices such as Standardized Precipitation Index (SPI), Standardized Precipitation and Evapotranspiration Index (SPEI) and Standardized Runoff Index (SRI) often fail at yielding precise information on detecting critical events and their associated impacts. This is due to the difficulty of capturing the complexity of extreme drought dynamics that evolve over diverse temporal (and spatial) scales, including short-term meteorological droughts, medium-term agricultural droughts and long-term hydrological droughts[24], as well as the non-physical aspects related to droughts (water management, irrigation, etc.). Moreover, an increase in drought severity and frequency is expected from future climate projections. Although regions over Europe are, to a certain extent, adapted to droughts, the level of change projected in CMIP5/6

[14] Stillman J.H. (2019), ve, the new normal: summertime temperature extremes will impact animals, ecosystems, and human communities, *Physiology*

[15] Onder et al. (2005), Different irrigation methods and water stress effects on potato yield and yield components, *Agricultural water management*

[16] Lobell et al. (2007), Historical effects of temperature and precipitation on California crop yields, *Climatic change*

[17] Dosio A. and E.M. Fischer (2018), Will half a degree make a difference? Robust projections of indices of mean and extreme climate in Europe under 1.5°C, 2°C, and 3° Global Warming. *Geophysical Research Letters*

[18] Russo et al. (2015), Top ten European heatwaves since 1950 and their occurrence in the coming decades, *Environmental Research Letters*

[19] Nairn, J.R. and R.J.B. Fawcett (2015), The Excess Heat Factor: A Metric for Heatwave Intensity and Its Use in Classifying Heatwave Severity. *International journal of environmental research and public health*

[20] Perkins, S.E. and L.V. Alexander (2013), On the measurement of heat waves, *Journal of Climate*

[21] Hong et al. (2018), Diagnosing physical mechanisms leading to pure heat waves versus pure tropical nights over the Korean Peninsula, *Journal of Geophysical Research: Atmospheres*

[22] van Loon A.F. and H.A.J. van Lanen (2012), A process-based typology of hydrological drought, *Hydrology and Earth System Sciences*

[23] Pedro-Monzonìs et al. (2015), A review of water scarcity and drought indexes in water resources planning and management, *Journal of Hydrology*

[24] Spinoni et al. (2016), *Meteorological Droughts in Europe: Events and Impacts - Past Trends and Future Projections*, Publications Office of the European Union, JRC100394

scenarios is likely to be beyond breaking point in many cases[25], which supports recent analysis of the risk related to extreme droughts in Climate Change Hotspots. CLINT will enhance the detection of extreme drought events by defining impact-based drought indices with ML algorithms that link the observed impacts of extreme droughts (e.g., reduction of electricity production or crop failures) with the candidate drivers of the event, including climatic, meteorological and hydrological variables over different spatial and temporal scales. CLINT will focus on specific Climate Change Hotspots that are particularly vulnerable to water supply (semiarid regions, river deltas, and snow-dependent river basins, Box 2).

Compound Events and Concurrent Extreme Events
Human and natural systems are often able to cope with a single EE, but they might be vulnerable when exposed to compound events (i.e. a combination of events, not necessarily extremes, that lead to significant impacts) and to concurrent EE (i.e. different types of EE occurring within a specific temporal lag as well as EE of the same type in two different locations within a specific time period)[26]. Compound events and concurrent EE have disproportionate impacts to humans and ecosystems[27]. From a risk perspective, the primary concern relates to events with additive or even multiplicative effects. These effects can result from mutually reinforcing cycles between individual events, such as the relationship between extreme drought and heatwaves, linked through soil moisture and evaporation[28]. Alternatively, they may develop through induced responses at distant areas of significant impact to the global system as in the case of concurrent hot extremes during summer 2018[29]. CLINT will prompt AI advances in the detection and characterization of the spatio-temporal evolution of compound events at the European scale and will explore global teleconnection mechanisms responsible for concurrent EE. Clint will bring improved understanding of concurrent EE by uncovering key drivers together with their interaction and interdependence. This will also support the development and analysis of high-impact scenarios arising from complex/nonlinear changes in the identified drivers.

1.1 Objectives

CLINT has the following five specific objectives and key deliverables:

Objective 1: A thorough analysis of how ML and AI can overcome the present limitations of C3S datasets for detection and attribution of EE under current and future climate.

Objective 2: To develop an AI-enhanced Climate Science to:

- Support the detection of spatial and temporal patterns, and evolutions of climatological fields associated with EE;
- Validate the physically based nature of causality discovered by ML;
- Support the attribution of single EE and observed trends in EE to man-made climate change and improve the quantification of future changes in EE.

Objective 3: To build AI-enhanced CS at European continental scale, based on the improved characterization of EE impacts across the WEF Nexus for estimating the vulnerability of EU climate change related policies.

[25] Toreti et al. (2019), The exceptional 2018 European water seesaw calls for action on adaptation, *Earth's Future*
[26] Zscheischler et al. (2020), A typology of compound weather and climate events. *Nature Reviews Earth Environment*
[27] Seneviratne et al. (2012), Changes in climate extremes and their impacts on the natural physical environment. *In Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*
[28] Kopp et al. (2017), Potential surprises – compound extremes and tipping elements, *In Climate Science Special Report: Fourth National Climate Assessment, Volume I*
[29] Vogel et al. (2019), Concurrent 2018 hot extremes across Northern Hemisphere due to human-induced climate change. *Earth's Future*

Objective 4: To demonstrate the potential of AI-enhanced CS in informing risk-aware decision-making and in supporting early warning systems at the local scale as key elements for adaptive capacity in different Climate Change Hotspots.

Objective 5: To put these services into operation via the Climate Services Information Systems supporting both the access to existing Copernicus climate data and the efficient processing of information through the CLINT AI-framework, as well as the development of CS prototypes and a demonstrator to be commercially exploited after the duration of the project.

1.2 Relation to the work programme

This proposal responds to the call "LC-CLA-12-2020 Advancing climate services", sub-topic "b) Detection and attribution of extreme events using Artificial Intelligence", which aims at exploring novel approaches for detection and localization of EE based on AI techniques, and quantifying their trends in current day and future climate change scenarios. A summary of how CLINT addresses the topic and the key challenges of the call is provided in Table 1.1.

Table 1.1: Call challenges and CLINT research focus.

Specific Challenge	CLINT response
There is a need to enhance action on adaptation with regard to strengthening scientific knowledge on climate	CLINT will advance the detection and localization of EE as well as the quantification of their impacts. This allows for a more robust characterization and improved predictability of EE and their impacts under the current climate conditions and different climate change scenarios. This will prompt timely and effective adaptation options.
A manner that informs Climate Services and supports decision-making, including the socio-economic analysis of adaptation options for key impact areas.	CLINT will develop innovative AI-enhanced CS to inform both EU policies and local users and decision-makers, identifying major vulnerabilities with respect to EE and exploring targeted adaptation options to reduce climate-related risks.
Create services that communicate and deliver bespoke critical climate information to better inform risk-aware decision-making and adaptation strategies	CLINT will set up an operational prototype of S2S detection and attribution of heatwaves/warm nights and extreme droughts to be tested during the project for exploitation as a CS by one of the SME partners (TCDF) after the project end. A better evaluation of future heat waves/warm nights and extreme droughts will also be included in the climate projections product of TCDF.
Actions should develop artificial intelligence techniques (e.g., deep learning) to detect spatial and temporal patterns and evolutions of climatological fields (e.g., temperature) associated with extreme events	CLINT will improve the detection as well as the characterization and predictability of EE and associated climate patterns by means of the most recent ML methods. The developed algorithms will be the core components of an AI framework that will allow processing big climate datasets.
Particular consideration should also be given to associated impacts and attribution to climate change	CLINT will develop process-oriented approaches and AI-enhanced services to better predict and project EE and their impacts, and to overcome current limitations for robust attribution of EE and trends in EE to climate change.

Actions should take advantage of data provided by the Copernicus programme	Partners in the consortium already have ongoing collaboration with the C3S Copernicus programme (see endorsement letter), which will ensure all the input data required by the project. Moreover, the AI framework will have specific components developed according to the most advanced standards that will facilitate adoption by web services (e.g. Copernicus CDS toolbox).

1.3 Concept and approach

(a) Concept

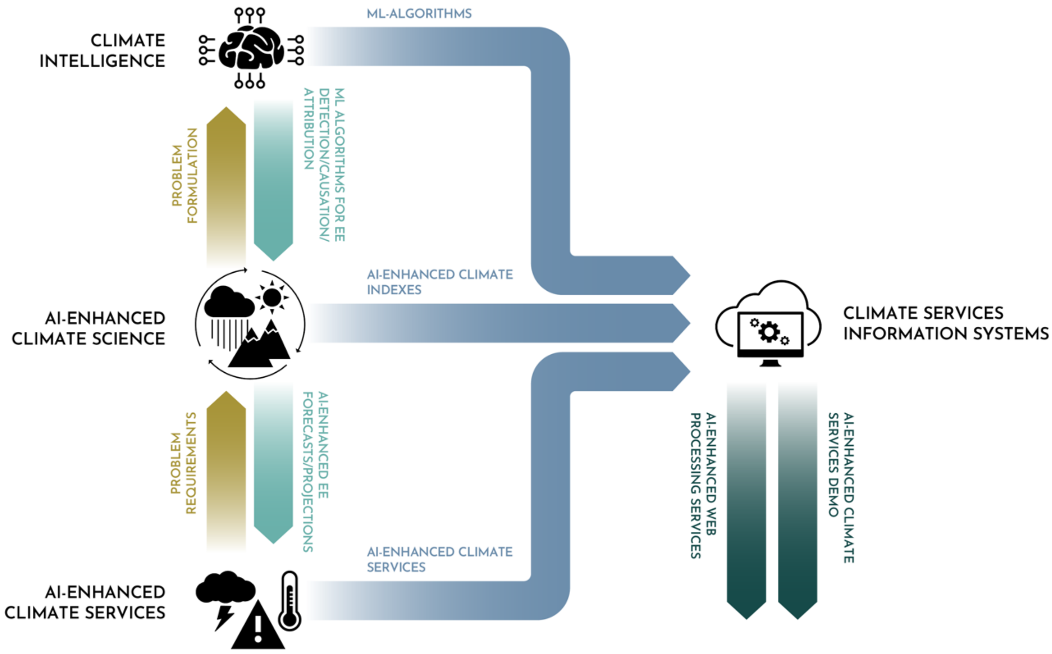

Figure 1: CLINT project concept and bottom-up flow chart.

CLINT proposes an AI framework to design innovative approaches for the detection, causation, and attribution of EE and the quantification of their impacts on different sectors under historical, forecasted and projected climate conditions by capitalizing on advanced ML techniques. To undertake this work, CLINT proposes a bottom-up structure (Figure 1) that aims at delivering a prototype of **AI-enhanced Climate Services** better addressing the WEF Nexus at the European scale (see Box 2) and informing local risk-aware decision-making in different Climate Change Hotspots (see Box 3). These case studies also provide the basis for co-designing CS matching end-user requirements (step 1, Figure 1) for distinct operational challenges on a broad spectrum of spatial scales (from continental to local) and temporal horizons, including historical/reanalysis data, S2S forecasts and climate change projections at regional (CORDEX) and global (CMIP5/6) scales. The CS requirements will represent the main inputs for the development of **AI-enhanced Climate Science**, that will study different EE including tropical cyclones, heatwaves and warm nights, and extreme droughts, along with compound events and concurrent extremes (see Box 1). The Climate Science will be supported by innovative ML algorithms developed in the **Climate Intelligence** component of the framework. The benefit of this AI-enhanced Climate Science will be demonstrated by quantifying the value of the resulting AI-enhanced CS on the WEF Nexus at the continental scale in order to strengthen EU climate-related policies. Moreover, the input and applicability of the AI-enhanced CS on strengthening adaptive capacity will be assessed at the local scale in different Climate Change Hotspots covering a diversity of areas where climate change signals overlap with exposed and vulnerable communities[30]. The selected hotspots include semiarid regions (i.e. Southern Africa, Iberian Peninsula), river deltas (i.e. the Netherlands), and snow-dependent river basins (i.e. Italian Alps) that are prone to severe impacts from EE under current and future climate conditions, and display a wide range of socio-economic development and adaptive challenges. Lastly, CLINT will develop **Climate Services Information Systems** supporting both the access and the efficient processing of existing climate data according to the most advanced open software and data standards (e.g. within the Copernicus CDS).

BOX 2: CLINT Climate Services addressing the WEF Nexus at EU scale at seasonal and climate projection horizons			
WEF Nexus	**Extreme Event**	**Impact modelling**	**Impact Indicator**
Water	Tropical Cyclones	E-HYPE hydrological model	Flood risk and Hydrological drought risk
	Extreme Droughts		
	Compound Events and Concurrent EE		
Energy	Heatwaves and Warm Nights	PRIMES-IEM energy model coupled with E-HYPE hydrological model	Power generation cost, load cuts, carbon intensity
	Extreme Droughts		
	Compound Events and Concurrent EE		
Food	Heatwaves and Warm Nights	JRC crop modelling system	Crop yield, crop suitability, areas of risks
	Extreme Droughts		
	Compound Events and Concurrent EE		

BOX 3: CLINT Climate Change Hotspots addressing local scale needs at S2S and climate projection horizons			
Hotspot	**Extreme Event**	**Impact modelling**	**Impact Indicator**
Semiarid	Extreme Droughts in the	Many-objective decision-	Energy production,

[30] De Souza et al. (2015), Vulnerability to climate change in three hot spots in Africa and Asia: key issues for policy-relevant adaptation and resilience-building research, *Regional Environmental Change*

regions	Zambezi Watercourse, Southern Africa	analytic model including dams and irrigation diversions	irrigation supply deficit
	Tropical Cyclones in the Zambezi Watercourse, Southern Africa	Warning system	Flood preparedness and flood risk
	Extreme Droughts in the Douro basin, Iberian Peninsula	River basin model including water storage and diversion infrastructures	Environmental flow restrictions
River deltas	Extreme Droughts in the Rhine delta, the Netherlands	Hydrological models of the Rijnland and Rhine and IJssel Water Systems	Irrigation supply deficit, crop production, soil moisture content, water quality
	Tropical Cyclones' potential impact on water systems of the Netherlands	Hydraulic models of the water systems	Flood preparedness
Snow-dependent basins	Extreme Droughts in the Lake Como basin, Italy	Many-objective decision-analytic model including dams, irrigation diversions, and a crop growth model	Irrigation supply deficit, crop production
	Heatwaves and Warm Nights in the Lake Como basin, Italy		
	Compound Events in the Lake Como basin, Italy		

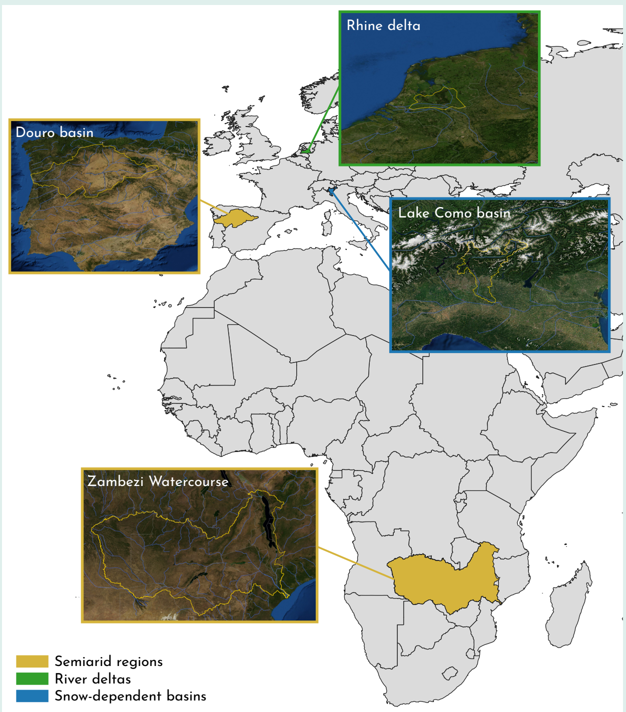

Figure 2: Map of CLINT Climate Change Hotspots.

Zambezi Watercourse

The Zambezi river basin is the fourth largest basin in Africa with an area of 1.32 million km^2 shared by eight countries (Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, and Zimbabwe) and populated by almost 40 million inhabitants. The high runoff in the upper part of the basin combined with a fall of more than 1000 m during its course to the ocean provide a good opportunity for hydropower production, which is currently exploited by an installed capacity of 5.5 TW. An additional 8.4 TW is planned by the end of 2023. Around 70% of this installed capacity is concentrated in two megadams, namely Kariba and Cahora Bassa. Two other dams, Ithezi-thezi and Kafue Gorge, are instead located in Zambia on the tributary Kafue River and contribute an additional installed capacity of 1.1 TW. Existing irrigated areas cover about 182,000 ha; major cultivated crops are sugar cane, rice, wheat, and maize. CLINT will provide AI-enhanced S2S hydroclimatic forecasts of extreme droughts for informing the multipurpose operation of the system (i.e. dams and irrigation diversions) that will contribute in improving the system performance in terms of hydropower production and irrigation supply, as well as in mitigating existing conflicts between these competing sectors. In addition, CLINT will generate an AI-enhanced warning system for tropical cyclones to improve flood preparedness in Mozambique, a region exposed to tropical cyclones impacts as demonstrated by the recent experience of the Cyclone Idai[31] in 2019, which resulted in an estimated 1.85 million people in need of humanitarian assistance and protection[32].

Douro River Basin

The Douro River Basin is the largest river basin in the Iberia Peninsula. It stretches over 98,000 km^2 and is shared by Spain (80% of its territory) and Portugal (20%). The Spanish part of the basin (Douro River Basin District) is markedly rural and is scarcely populated. There are over 65 large dams that are used to satisfy the water demands in the basin. The largest water consumer is irrigated agriculture that accounts for 93% of consumptive water demand over 500,000 hectares of irrigated land. The hydropower capacity is approximately 3,866 MW distributed across 171 active plants, which corresponds to about 22% of Spain's installed hydropower capacity. Over 23% of the basin is protected under European Union Directives for biodiversity conservation, including 86 Sites of Community Importance and 52 Special Protection Areas under the EU Natura 2000 Network. As of the year 2013, minimum environmental flows have been defined in the vast majority (98%) of the Douro river-type water bodies. Droughts are one of the most recurrent and high-impact EE affecting Iberia, due to the uneven distribution of limited water resources and the strong dependence of irrigated crops and hydropower production. For example, the severe 2016/2017 drought affected the agricultural production of different crops in Spain, including tomatoes and wine grapes, and hydroelectric power production reached a historical minimum[33]. CLINT will provide AI-enhanced S2S hydroclimatic forecasts of extreme droughts for informing decisions about water allocation among users and the application of restrictions to established e-flows in case of extreme drought.

Rhine Delta

CLINT will address CS targeting two local water authorities in the Rhine Delta of the Netherlands. The Rijnland water board covers an area of about 1000 km^2, in the western part of the Netherlands, between The Hague and Amsterdam, including the North Sea coastline and crucial economic infrastructures such as Amsterdam's Schiphol international airport. The area has 1.3 million inhabitants. In Rijnland, 72% of the land is occupied by low-lying land-reclamation areas, 15% by free draining areas and 8% by dunes. A storage basin consisting of interconnected canals and lakes, occupies 45 km^2. Prolonged dry spells in combination with low-flows of the Rhine River lead to a shortage of surface water, potential dike instability along the storage basin (leading to floods), and salinity problems. The intake of extra surface water via alternative supply routes may then need to be organized in coordination with neighbouring water authorities. The Rijn en IJssel water board covers an area of 2000 km^2 in the eastern part of the Netherlands. Areas with mainly sandy soils are located

[31] Emerton et al. (2020), Emergency flood bulletins for Cyclones Idai and Kenneth: a critical evaluation of the use of global flood forecasts for international humanitarian preparedness and response, *International Journal of Disaster Risk Reduction*

[32] World Health Organization Africa (2019), Tropical Cyclone Idai Mozambique Situation Report

[33] García-Herrera et al. (2019), The European 2016/2017 drought. *Journal of Climate*

east of the river IJssel, and have little surface water. During the dry summers of 2018, 2019 and 2020 these areas were subject to low soil moisture content and groundwater tables, with large impact on both agriculture and environment. CLINT will provide AI-enhanced S2S hydroclimatic forecasts of extreme droughts to support these two water authorities' risk-based management of surface water allocation, alternative surface water supply routes and groundwater abstraction. Drought adaptation strategies will also be studied using AI-enhanced climate projections for extreme droughts. Historically, however, the Netherlands have been fighting floods more often than droughts. Wind is a relevant factor in the design of flood defence infrastructure for The Netherlands' main rivers and lakes (IJsselmeer/Markermeer) and the coast. In current climate, most extreme storms occur between October and April. In recent years, several cyclones landed the European west-coast while being classified as tropical cyclones almost all the way up to landfall, for example Ophelia (2017), Leslie (2018) and Lorenzo (2019). It is not well understood how these storms are different (e.g. timing, duration) and whether they will affect flood risk in the Netherlands. CLINT will provide climate projections for tropical cyclones and their extra-tropical transition towards the European coast to study implications for the Dutch rivers, lakes and coast.

Lake Como basin

Located in the Italian Alps, the Lake Como basin is a highly controlled water system, including a large regulated lake (active capacity 247 Mm^3) serving a wide irrigation-fed cultivated area (1,320 km^2), where maize is the most widely grown and productive crop (52% of the area and 1.5 Mton/year). The hydro-meteorological regime is typical of sub-alpine regions, characterized by dry periods in winter and summer, and flow peaks in late spring and autumn fed by snowmelt and rainfall, respectively. Snowmelt during May-July is the most important contribution to the accumulation of the seasonal storage, which is then used for irrigation supply in the summer during the peak demand period. The latter often exceeds the natural water availability and makes the role of the lake operation paramount for the system. The regulation of the lake is driven by two primary competing objectives: water supply, mainly for irrigation, and flood control along the lake shores. The agricultural districts downstream prefer to store snowmelt in the lake to satisfy the peak summer water demands, when the natural inflow is insufficient to meet irrigation requirements. Yet, storing such water increases the lake level and, consequently, the flood risk. Additional interests are related to navigation, fishing, tourism, and ecosystems, that further challenge the existing water management strategies and motivate the search for more efficient solutions relying on hydroclimatic services. CLINT will provide AI-enhanced S2S hydroclimatic forecasts of extreme droughts indices for informing the operation of the lake that will contribute to improve the reliability of the irrigation supply, particularly in facing severe dry conditions, as well as to mitigate existing conflicts between competing sectors. Extreme heat is another factor of risk for agriculture in the area, since early or in-season heatwaves and summer persistent anomalously warm nights may jeopardize the yield. Finally, the co-occurrence of droughts and warm extremes in the region produces high risks related to compound events. CLINT will generate AI-enhanced S2S forecasts of heatwaves and warm nights, also including compound events, to inform farmers agricultural practices.

CLINT represents a hybrid system, based on an innovative AI framework aiming to advance the detection, causation, and attribution of diverse EE via a combination of novel and well-established ML algorithms. The CSIS will support both the access and the efficient processing of existing climate data tailored to the C3S, and links with CEMS. The whole project is therefore classed under a Technology Readiness Level (TRL) between 2-6, although individual project modules may involve different TRLs, as detailed in Table 1.2.

Table 1.2: Technology Readiness Level of the CLINT modules.

CLINT module	Technology Readiness Level
Climate Intelligence	CLINT will build on existing ML and AI algorithms adapting them to the specific requirements of the Climate Science: detection, causation, and attribution of EE (TRL 3). The AI-

	framework will also develop novel approaches and algorithms to improve extreme event specific data analytics (TRL 2).
AI-enhanced Climate Science	CLINT aims to exploit and improve existing detection and causality methods of EE (TRL 3) and to develop new ones (TRL 2) for a more efficient investigation of EE, their drivers and physical processes. This AI-enhanced CS will also develop for the first time novel methodologies for the attribution of EE and trends in EE to anthropogenic factors (TRL 1) and test them with historical EE (TRL 2). CLINT will also provide more informative projections of future changes in EE and concurrent EE (TRL 3).
AI-enhanced Climate Services	CLINT will augment existing and develop new CS for users on the pan-European and local scales. Despite some of the existing CS are already in use (TRL 9), enhancement with AI will be employed for the first time, such that the starting point is TRL 2, with the ambition to reach TRL 5 through validation for the case studies defined.
Climate Services Information Systems	CLINT will also develop the software components using templates (birdhouse – cookiecutter, TRL 5) tailored for C3S deployment and following Open Geospatial Consortium (OCG) Standards (TRL 5) recommended by the United Nations Global Geospatial Information Management. Implementations of ML and AI algorithms into CSIS have been explored with the latest OGC-Testbed 16 ready to build upon for CLINT (TRL 2). Data - Visualisation developed and tested for PAVICS project will be adapted for deployment in CLINT (TRL 6). CLINT will also implement and test an operational prototype for commercial exploitation. Two production modes will be set up on a cloud environment: one based on S2S forecast and one based on climate projections using a coherent and seamless data production scheme at the global level (ERA5 based resolution). The ambition is to increase the TRL level to 6.

Links with national and international research and innovation activities
CLINT consortium partners are involved in many past and ongoing research projects that provide relevant input for the topic of the call, and CLINT will build directly on knowledge gained and output/deliverables from these projects (see Table 1.3).

Table 1.3: Main Research and Innovation activities feeding CLINT project.

Project Name	Project output used by CLINT	Partner
H2020 IMPREX: IMproving PRedictions and management of hydrological EXtremes	CLINT will take advantage of lessons learnt from the development of CS in different impact sectors.	POLIMI, SMHI, HKV, ECMWF, HZG
H2020 DAFNE: A Decision-Analytic Framework to explore the WEF Nexus in complex and transboundary water resources systems	CLINT will exploit lessons derived from the analysis of the water-food nexus in Africa under changing climate and society. DAFNE will also provide modelling tools upon which CLINT will build the evaluation of CS.	POLIMI
H2020 S2S4E: Sub-seasonal to Seasonal climate forecasting for Energy	CLINT will integrate the expertise in terms of S2S forecasting in the development of forecast prototypes of EE.	SMHI, TCDF

H2020 CLARA: Climate forecast enabled knowledge services	CLINT will benefit from the user co-design expertise of this project in building upon C3S forecasts and sectoral information systems.	CMCC, SMHI, TCDF
H2020 PRIMAVERA: a new generation of high-resolution global simulations	CLINT will build on PRIMAVERA output to tune the developed ML tools at different horizontal resolution.	CMCC, SMHI, ECMWF, DKRZ
H2020 IS-ENES3: Infrastructure for the EU Network for Earth System Modelling	CLINT will exploit lessons derived from the development of a EU e-infrastructure supporting the climate modelling as well as the climate impact community.	DKRZ, CMCC
C3S WaterSIS - operational C3S Water SIS (SWICCA) C3S Global Impacts Service C3S_433_Lot2 C3S 34a (CP4CDS) C3S 34b (CORDEX4CDS) C3S 51 Lot 4 and C3S 428j	CLINT will take advantage of recently developed operational services and quality-controlled data, such as seasonal forecasts and climate impact indicators for water managers in Europe and the globe, which will represent the basis for developing evolved CS.	SMHI, DKRZ, TCDF, CMCC, ECMWF

(b) Approach

The project is structured in nine Work Packages (WPs) as illustrated in Figure 3. WP2-5 will contribute to the CLINT project objectives 1 and 2, WP6 to objective 3, WP7 to objective 4, and WP8-9 to objective 5.

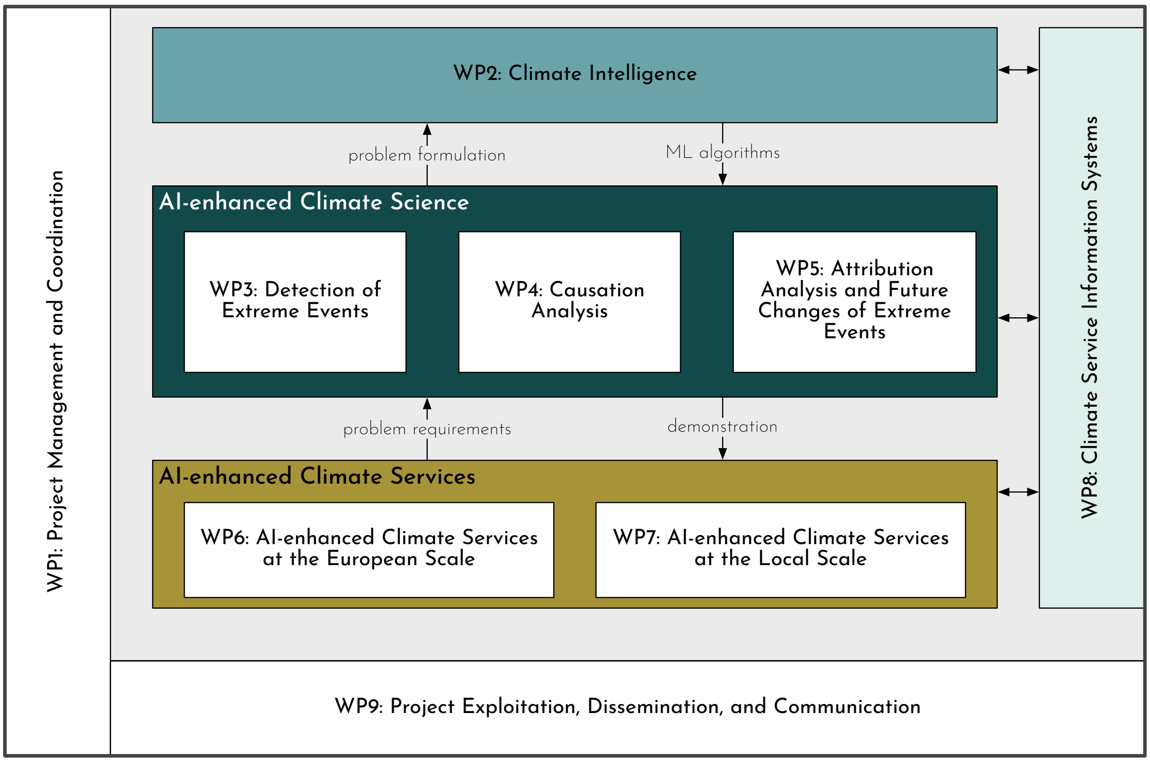

Figure 3: CLINT project structure.

WP1: Project Management and Coordination (Leader: POLIMI)
This WP will create and maintain the conditions to ensure the effective and timely implementation of the project goals. To this end, WP1 will work towards facilitating clear and effective flow of information between consortium members, managing the scientific coordination between WP and organizing regular Project meetings. WP1 will also be responsible for ensuring the quality and punctuality of scientific outputs, in particular of project reports to the EU, undertaking the risk management of the project, monitoring the progress of the planned activities, as well as anticipating and addressing potential issues.

WP2: Climate Intelligence (Leader: POLIMI)
This WP aims at developing novel and improving existing ML algorithms and AI methodologies to support the detection, causation and attribution of EE by efficiently processing big climate datasets and discovering spatial and temporal patterns, and evolutions of climatological fields associated with different categories of EE. Building on the ML techniques that have proven most successful in climate-related applications (e.g. support vector machines, Bayesian deep learning and super-resolution convolutional neural networks), this WP will develop novel ML approaches for feature selection/extraction, causal discovery and model reduction suited to climate problems related to EE. Finally, the WP will explore the potential of deep learning models to predict EE over different lead times and to reconstruct past EE. The WP will work in close connection with WP3-5 to develop specific tools for each type of EE and concurrent EE, and with WP6-7 to validate them extensively over different spatio-temporal scales and several multisectoral real-world contexts.

WP3: Detection of Extreme Events (Leader: CMCC)
This WP aims at isolating EE from reanalysis and model output by imposing an ML-lens onto existing detection techniques/indices, using the AI techniques developed in WP2 in order to expand current knowledge on the complex relationships between EE and large-scale fields. WP3 will focus on different classes of EE: tropical cyclones, heatwaves and warm nights, and extreme droughts, also considering compound events and concurrent EE (see Box 1) with the aim to facilitate their investigation with different datasets and time horizons, including observational-based products, S2S forecasts and long-term (centennial) climate projections provided by the Copernicus CDS. For each type of EE, the WP will focus on its detection by improving the existing procedures used to classify an event as a tropical cyclone/heatwave/warm nights/extreme drought, and identifying the large-scale patterns related to the EE occurrence. The so-detected EE and their large-scale drivers will be the basis for further developments in WP4-5.

WP4: Causation Analysis and Physical Interpretability of Extreme Events (Leader: HZG)
Physical interpretability of results is a key problem in the application of ML methods to climate. The inference of physical causality can often be compromised by the complexity of ML algorithms and their inability to legitimately deduce physically meaningful cause-and-effect relationships. WP4 aims at validating the physical relationships between predictors and EE (including concurrent EE) identified in WP3 and investigating with climate simulations and ML algorithms the true physical mechanisms at the origin of the EE. Causality will be explored both using a traditional model-based approach and novel ML methods based on data-driven causal inference. The first avenue will use a suite of climate model simulations to validate the association between the large-scale fields and EE detected in WP3; the second approach will rely on the most recent ML developments (WP2) in the field of causal discovery and causal representation learning.

WP5: Attribution Analysis and Future Projections of Extreme Events (Leader: CSIC)
This WP will develop process-oriented and ML-based approaches to set on a firm footing the physical understanding of EE (including concurrent EE), their links with anthropogenic forcing and their future changes. It will build upon the ML methods developed in WP2 to infer associations between large-scale patterns and the different EE detected in WP3 (Box 1). The retrieved event attributions will be dissected through the cause-effect relationships validated in WP4 in order to detect human fingerprints in the causal chain of EE. A selection of historical EE that affected the European WEF Nexus (Box 2) and the Climate Change Hotspots (Box 3) will be included in the attribution analysis. In addition, ML algorithms will be exploited to improve the detection of observed trends in the spatial patterns of extreme indices and EE, and associations with anthropogenic forcing. Finally, the WP will also quantify future changes in each class of EE and concurrent EE, using the AI techniques to uncover the climate change responses in the large-scale drivers of EE. This AI-enhanced Climate Science will be exploited to construct best- and worst-case scenarios of EE changes for different levels of global warming, therefore achieving tailored developments to WP6-7, as well as demo service to be implemented in WP8.

WP6: AI-enhanced Climate Services at to Foster Adaptation at the Pan European Scale (Leader: SMHI)
This WP focuses on innovating existing CS, supporting several EU policies in the WEF Nexus, by using tools, methods and knowledge developed and gained in WP 2-5. The focus will be on the whole European continental scale (see Box 2). Large scale complex mechanistic models of the European hydrological (E-HYPE), agricultural (JRC crop modelling and forecasting systems) and energy (PRIMES) systems will be used and innovated to characterise, estimate, predict and project EE impacts and address the needs and the gaps of current EU policies including, among others, the Climate Adaptation Strategy, the Common Agricultural Policy, the EU floods directive, the EU water directive (REFIT), the Clear Planet for all strategy. A circular interaction between this WP and the previous ones will ensure continuous exchange and feedback of information required to achieve tailored developments of the ML techniques. The innovation of these existing systems will not be limited to the integration of novel ML methods, but an AI-revolution will be put in place to bring these services to the forefront of CS.

WP7: AI-enhanced Climate Services to Foster Adaption at the Local Scale (Leader: IHE)
This WP will develop tailored and sector specific AI-enhanced CS relying on improved detection and attribution of EE that will add value through better informed decision-making on climate adaptation options at the local scale. The work will focus on the impacts of EE in different Climate Change Hotspots (see Box 3) where there is a disproportionately high climate risk due to a combination of exposure to EE and socio-economic vulnerability, further exacerbated by a rapidly growing and increasingly urban population and projected increase in EE. Building on existing S2S forecast capabilities, climate projections and impact models developed in previous H2020 projects (see Table 1.2), this WP will demonstrate with a proof of concept the operational value of AI-enhanced CS over different temporal scales (e.g. S2S forecasts and climate projections). The AI-enhanced CS prototypes will be co-designed with the end-users and tested pre-operationally across different case studies featuring distinct operational challenges

WP8: Climate Service Information Systems (Leader: OGC)
This WP aims at developing software prototypes for CSIS. The components will be created in co-development with WP2 (ML algorithms), WP3-5 (AI-enhanced Climate Science), and WP6-7 (AI-enhanced CS). Software prototypes will be developed as Web Processing Services (WPS) in respect of the open standards to ensure deployment into existing European data

infrastructures like C3S, EOSC[34] or Wekeo[35]. The services will be developed within the open source project ‘birdhouse’, the WPS framework which is already providing several components of the C3S technology. These components will be in line with the code of conduct, guidelines and recommendations already established in the birdhouse project as a required condition to be usable in any kind of technical CSIS following the OGC standards, e.g. for C3S as well as the Copernicus Sectoral Information System. Developed software components of WP8 will be publicly available within the birdhouse project under a GPL3 License. WP8 will also coordinate data repository and management for the whole project duration.

WP9: Exploitation, Dissemination, and Communication (Leader: TCDF)
This WP aims at designing and implementing an effective outreach plan to promote the project activities and to disseminate the new knowledge generated in the project. This is achieved by a broad range of dedicated instruments based on state-of-the-art technologies to tailor the communication for both specialised audiences and the general public. This approach will ensure that the project’s results are widely promoted and disseminated to diverse audiences, including policy-makers at the European level and in the local Climate Change Hotspots, the scientific community, adaptation practitioners, Copernicus users and other professionals from both the public and private sector. A particular focus will be on the definition of exploitation options either in terms of potential uptake of the CLINT outcomes by the Copernicus programme as well as by the SME partners and potentially other public and private entities.

WP10: Ethics requirements (Leader: POLIMI)

The WP aims to ensure compliance with the 'ethics requirements' hat the project must comply with.

Sex and Gender Analysis
The CLINT participating organisations actively promote equal representation of men and women in employment and decision-making and removing institutional barriers to gender equality. All organisations have an equal opportunity policy implemented and many are certified for their equal opportunity practice and procedures. CLINT will ensure women’s participation as active members in the different consortium entities. In the current structure, approximately 33% of all involved people are female (see Section 4.1). We support the mainstreaming of gender issues in research and policy, as a balanced gender composition helps the sustainability and quality of European adaptation policies. We will pay attention to gender equality and diversity by employing a recruitment policy and working environment that is welcoming for female candidates. Gender equality will be also considered in the appointment of the project Advisory Board. On the other hand, the research topic dealt with by CLINT, i.e. better characterization of EE, and correspondingly the enhancement of EE related CS and CSIS, through ML does not seem to include explicit gender dependent issues.

1.4 Ambition

The applications of AI to Climate Science has spurned substantial improvements and generated interesting new problems and challenges for ML algorithms[36]. Dually, modern ML tools have the potential to set a decisive step in our understanding of the climate system and ongoing climate change[37]. CLINT ambition is to introduce a novel framework of tools to allow CS to

[34] https://www.eosc-hub.eu/
[35] https://www.wekeo.eu/
[36] Monteleoni et al. (2011), Tracking Climate Models, *Statistical Analysis and Data Mining*.
[37] Reichstein et al. (2019), Deep learning and process understanding for data-driven Earth system science. *Nature*

handle EE with innovative contributions for the detection, causation and attribution of different EE, including the quantification of their associated impacts at different spatial scales. We strive a seamless implementation of ML to dedicated CS in support of EE detection and attribution to inform EU policy strategies and local decision-making by enhancing adaptive capacity and reducing vulnerability to EE in a changing climate.

Machine Learning to advance discovery in Climate Science: over the past decade, we have witnessed impressive progress in AI research and, in particular, in the ML field, where, especially thanks to the development of deep learning techniques, extraordinary results have been achieved in various areas (e.g. computer vision, natural language processing, self-driving cars and many others). Having plentiful climate data[38], climate scientists are increasingly, but still slowly, relying on ML techniques to improve accuracy and reduce the computational cost of climate models[39,40]. Nonetheless, up to now, ML has proven more effective in learning weather models for short-term predictions at local scales than in long-term projections over large spatial domains[41], although climate applications are also emerging[42]. CLINT will establish new conceptual paths to process the large amount of climate data currently available and take into effectively consideration both long-term and spatially distributed EE. CLINT will also contribute with new ML algorithms to data-driven causal discovery by using approaches based on the estimation of the directed information[43]. Finally, CLINT will develop novel ML methods for the attribution of EE to human-made climate change, a field where current methodologies hamper confident statements for some types of EE and the use of ML is still in its infancy[44,45].

Detection of Extreme Events: successful detection of EE in gridded datasets is fundamental for a full understanding of the climate system[46,47] Recent advances in computing power and research in data sciences enabled us to look at this problem with a different perspective from what was previously possible[48] also in terms of their linkage with the large-scale circulation[49]. These challenges involve both algorithms development and big data management. The ambition is to improve our ability to detect climate extremes, such as tropical cyclones, heatwaves and warm nights, and extreme droughts, along with compound events and concurrent EE, in both model and reanalysis data at different horizontal resolutions, by improving existing methodologies[50,51] and designing new approaches based on ML. The

[38] Monteleoni et al. (2013), Climate informatics: accelerating discovering in climate science with machine learning, *Computing in Science & Engineering*..

[39] Rolnick et al. (2019), Tackling climate change with machine learning, *arXiv:1906.05433.*

[40] Jiang et al. (2020), Improving AI system awareness of geoscience knowledge: Symbiotic integration of physical approaches and deep learning, *Geophysical Research Letters*

[41] McGovern et al. (2017), Using artificial intelligence to improve real-time decision-making for high-impact weather, *Bulletin of the American Meteorological Society*

[42] Nowack et al. (2020), Causal networks for climate model evaluation and constrained projections, *Nature Communications*

[43] Vreeken J. (2015), Causal inference by direction of information, *In Proceedings of the 2015 SIAM International Conference on Data Mining*

[44] Barnes et al. (2019), Viewing Forced Climate Patterns Through an AI Lens, *Geophysical Research Letters*

[45] Székely et al. (2019), A direct approach to detection and attribution of climate change, *arXiv:1910.03346*

[46] Horn et al. (2014), Tracking Scheme Dependence of Simulated Tropical Cyclone Response to Idealized Climate Simulations, *Journal of Climate*

[47] Barbier et al. (2018), Detection of Intraseasonal Large-Scale Heat Waves: Characteristics and Historical Trends during the Sahelian Spring, *Journal of Climate*

[48] Matsuoka et al. (2018), Deep learning approach for detecting tropical cyclones and their precursors in the simulation by a cloud-resolving global nonhydrostatic atmospheric model, *Progress in Earth and Planetary Science*

[49] Scoccimarro et al. (2020), The typhoon-induced drying of the Maritime Continent, *Proceedings of the National Academy of Sciences*

[50] Kretschmer et al., (2016), Using causal effect networks to analyze different Arctic drivers of midlatitude winter circulation, *Journal of Climate*

[51] Toreti et al. (2019), Concurrent climate extremes in the key wheat producing regions of the world. *Scientific Reports*

provision of more reliable and fast tools will streamline the development of these new CS, and to support impact studies and planning of adaptation strategies.

Causation in Extreme Events detection: data-driven causation analysis is at the forefront of research of ML methods[52,53], but they have barely been explored in climate research[54], even less so for EE. Our ambition in CLINT is to develop ML-climate hybrid approaches by adapting and applying causality algorithms to the mostly unexplored field of EE, and complementing them with physical understanding from model simulations in order to identify the physical mechanisms that give rise to EE and concurrent EE. If successful, this will advance not only the methodological aspects of ML, but also be extreme useful for improving the analysis and prediction of EE and to inform CS.

Attribution of Extreme Events: the occurrence and changes in EE, and their attribution to climate change have been extensively studied in the last decades[55], since they directly impact societies on local and regional scales, where people experience climate change. However, the difficulty to deal with the large number of factors at the origin of EE and their interactions has contributed to elusive attributions of some EE to climate change[56] and to large uncertainties in future projections[57], posing limitations to the development of effective adaptation strategies. CLINT will make a decisive step forward in our capabilities of EE attribution by coupling process-oriented approaches with modern ML techniques to detect trends and human fingerprints[58] in the chain of processes responsible for different types of EE. CLINT will also employ state-of-the-art climate model ensembles to dissect plausible future changes in the drivers of EE and concurrent EE, and use them in a physically coherent way to quantify future changes of EE.

AI-enhanced Climate Services: a large amount of data and information is available in the C3S setup for a large target group of users and for regional/national products tailored to address the specific needs of local users. However, providing effectively useful sectorial CS procedures at different spatial-temporal scales is a challenging task[59]. Current challenges in the predictive skill at different time ranges, the limited knowledge of users on interpreting climate data and the lack of rigorous impact assessments of EE[60] are factors that halt the emergence of actionable climate risk management and improved decision-making[61]. CLINT aims at bringing an AI-revolution into these existing systems to achieve a robust characterisation of EE impacts and improve their predictability under transient climate conditions, also considering concurrent and compound events. This innovation will make a leap in CS, including the identification of areas of concerns[62] as well as risk and impact assessments[63]. Moreover, the methods developed in CLINT will bridge the gaps that currently inhibit a widespread use of CS for supporting both EU policies and local decision-making, by addressing multi-sectoral interests across the WEF

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[52] Schölkopf B. (2019), Causality for Machine Learning, *arXiv:1911.10500*

[53] Runge et al. (2019), Detecting and quantifying causal associations in large nonlinear time series datasets, *Science Advances*

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[59] Contreras et al. (2020), Advances in the Definition of Needs and Specifications for a Climate Service Tool Aimed at Small Hydropower Plants' Operation and Management, *Energies*

[60] Street R.B. (2016), Towards a leading role on Climate Services in Europe: a research and innovation roadmap, *Climate Services*

[61] Samaniego et al. (2019), Hydrological forecasts and projections for improved decision-making in the water sector in Europe, *Bulletin of the American Meteorological Society*

[62] JRC MARS Bulletin 27/6, 2019.

[63] Ciscar et al. (2018), *Climate impacts in Europe*, Publications Office of the European Union, JRC112769

Nexus, different time horizons (S2S and centennial climate projections), and the gap between large-scale products and local applications' requirements.

Climate Services Information Systems: existing data processing portals have a set of relatively simple processes/analytics to be executed by expert users. CLINT is going to demonstrate fully automatic EE assessments with the AI-based algorithms deployed within the service. The ambition is in the scalability of the system in order to provide EE assessments from local to continental scale as well as from short-term forecasts to long-term projections to serve different user needs, all over the same backend architecture.

Our consortium has experience in AI, Climate Science and CS, and the potential to produce relevant scientific innovations as the partners have an excellent publication record from leading journals in various research fields, including Science, Nature, Nature Climate Change, Nature Sustainability, Science Advances, Scientific Reports, Earth's Future, Water Resources Research, Climate Services, Climate Dynamics, Journal of Climate, Bulletin of the American Meteorological Society, Geophysical Research Letters, Environmental Research Letters, Machine Learning, Journal of Machine Learning, etc.

2. Impact

2.1 Expected Impacts

CLINT is designed to develop an AI framework for evolving Climate Science and Services by improving the understanding and predictability of EE and by quantifying their impacts on a number of targeted climate-related sectors, under both historical and projected climate conditions and across different spatial scales, from the whole European to the local scale in different Climate Change Hotspots. Specifically, the contributions of CLINT to the expected impacts mentioned in the call text and the associated Key Performance Indicators (KPI) for their quantification are:

Expected Impact 1: **Enhanced adaptive capacity, from pan-European to local scale**

The current limited understanding of the physical drivers of weather and climate EE acting across different spatio-temporal scales, the low predictive skill of EE at S2S horizon, and the large uncertainty affecting the attribution of EE to climate change and the quantification of their future changes represent major challenges to the adoption of effective adaptation strategies in climate-sensitive sectors. CLINT will provide a new means for detection, attribution and quantification of future changes in EE based on a suite of ML techniques coupled with physical understanding of key processes, geared to the deployment of innovative AI-enhanced CS supporting solutions compatible with Sustainable Development Goals and the Sendai framework. Moreover, the methods applied in CLINT will bridge the gaps that currently inhibit the widespread use of CS for EE, including the discontinuity between the large-scale climate drivers and the local impacts of EE, and the interdependence between water, energy and food sectors.

KPI.1: Improvement in the impact indicators listed in Box 1-2 generated by the AI-enhanced CS provided by CLINT.

Expected Impact 2: Reduced vulnerability to climate change

CLINT will develop a prototype of AI-enhanced CS supporting EU policies in the WEF Nexus, such as the EU floods directive, the new Green Deal, the Climate Adaptation strategy, the Common Agricultural Policy, the Clean Planet for all strategy, the Energy Roadmap, and the

Low Carbon Economy Roadmap. In fact, CLINT will contribute to achieve higher predictability of EE, more informative climate projections of EE and associated impacts, and to define and test targeted sectorial adaptation strategies. These CS will be strategic to support the climate ambition of the forthcoming policies (e.g. the new CAP).

KPI.2: Number of proofs of concept applicable to EU initiatives, such as CEMS-Flood, CEMS-Drought, Energy Roadmap, MARS Crop Yield Forecasting System.

Expected Impact 3: Enhanced actions on adaptation

The demonstration of the value of AI-enhanced CS produced by CLINT at the European scale as well as in different Climate Change Hotspots will entangle ML methods and EE analysis with more informed adaptation measures. While short- to medium-term forecasts have already been shown to improve EE management in many public agencies and private sectors, linking S2S forecasts and climate projections, and exploring their use for EU policy-making and/or in local applications still has to be implemented and communicated. CLINT will bring novelty by synergizing frameworks for S2S forecasts and climate projections in a seamless communication approach. This will result in a new form of CS supporting an enhanced action of adaptation informed by continuous and consistent EE information over different time horizons.

KPI.3: Number of AI-enhanced CS synergizing forecasts and climate projections applications.

Expected Impact 4: Strengthened scientific knowledge on climate

CLINT will develop an AI framework implementing a suite of ML techniques able to improve, and possibly replace, traditional detection and attribution methods for several types of EE. The developed algorithms will allow filling gaps in observational datasets, discovering patterns and teleconnections associated with EE, including undetected spatial interrelationships between different types of EE. Novel attribution methodologies will be explored to improve the detection of observed trends in EE and the quantification of human fingerprints in individual EE once they have happened, advancing in our current capabilities to attribute EE to climate change. CLINT will also develop process-oriented approaches to robustly link projected climate change and the changing frequency and intensity of EE, ultimately delivering comprehensive projections of future changes in EE based on feasible physical responses of their drivers, and making unique contributions to pin down the key processes governing the current uncertainty in future projections of EE. CLINT will have an additional impact on the scientific and academic sector by strengthening the link with the Copernicus climate-related services (C3S and CEMS), and fostering effective knowledge transfer between researchers/scientists and service providers. The scientific robustness is the key element for CLINT success, since the developed AI methods will ensure technically/computationally efficiency and robustness for a potential uptake to operational services. CLINT will disseminate results and techniques to the wide academic and scientific community, including scientific organisations and initiatives in which the partners' reputation is very well established (e.g. IAHS, Panta-Rhei, HEPEX, H-SAF, GFP), with the aim to influence others to participate and scientifically contribute.

KPI.4: Number of dissemination tools/materials developed for the academic and scientific user groups.

Expected Impact 5: Better informed CS and decision-making

Despite recent investments in building European-wide outlooks and CS, there is still room for better aligning users' expectations and maximum level of usable information that can be delivered by these services for local decision-makers. Continental scale impact assessments are driven by coarse process representation and spatial differentiation, often having limited accuracy in reproducing local impacts. CLINT will engage with different local users in the Climate Change Hotspots to put forward AI-enhanced modelling chains for local impact-based predictions and projections of EE. This effort will create a communication link with local users, foster trust, and lead to enhanced decision-making and enlargement of business opportunities. This strategy sets out the affordable stages that are necessary to foster the co-development and co-evolution of the CS chain, i.e. from service providers and developers to policy-makers and local users. At the same time, the integration of the CLINT AI tools into the Copernicus services (C3S and CEMS) and/or Climate Services SMEs supported by OGC WPS will contribute to add value to and enhance the existing European products for local assessment by practitioners and decision-makers. In this way, CLINT will evolve, complement, and broaden the Copernicus programme through product extension and service improvements. This is a crucial step to also foster the uptake of Copernicus services by business and entrepreneurs.

KPI.5: Number of outputs that could be integrated into the Copernicus services and other CS providers.

Barriers and obstacles to impact achievement

A number of current and potential barriers and risks to the achievement of the CLINT impacts have been taken into account in the planning of the project. These are described briefly here and discussed more in detail in Section 3.2, along with the means for addressing them.

- *Conservative attitudes by public and private institutions to transform their key business functions* - CLINT will move users (including Copernicus) from traditional approaches and practices in favour of innovative AI developments by demonstrating the value of AI-enhanced services. They can build business value in the CLINT products and prototypes, and stimulate competitiveness and growth of the market.
- *Data access related problems* - C3S hydro-meteorological seasonal data and climate projections are available through the CDS platform. S2S forecasts are available at no cost through ECMWF and also through the S2S project database. CEMS seasonal hydrological forecasts are available through the CDS platform. Downscaled CMIP climate projections of essential surface variables are brought in and provided to the project by TCDF.
- *Changes in data standards* - Progress on Copernicus data standards is contingent on factors outside the consortium. However, several consortium partners are active in many of these standardization processes through their involvement in the Copernicus services (particularly C3S WaterSIS, CEMS-Drought and CEMS-Floods), which will allow anticipating any changes and developing mitigation strategies.

2.2 Measures to maximize the impact

Early interaction with the final end-users that will benefit from the AI-enhanced CS developed in CLINT will maximize the impact of the project results and ensure the uptake of the results. We have therefore chosen a combination of measures for Dissemination, Communication, and Exploitation. These activities (see Table 2.2) will involve all consortium partners and their respective staff, including researchers.

Table 2.2: CLINT matrix for Dissemination, Communication, and Exploitation.

Who?	What?	How?

Who is the target audience? Who should be involved in communication processes?	What information should be delivered?	Which mechanisms will assist our strategy?
Scientific Community, Copernicus programme, Copernicus users in both public and private sectors, local end-users, EU policy-makers.	One-size fits all does not necessarily work. Each of the target groups identified in the Outreach Plan will be reached via tailored messages and suitable channels.	Website, social media, workshops and webinars, scientific publications, policy brief.
When?	**By whom?**	**Where?**
Timing is key. CLINT partners will ensure an effective timing of the dissemination activities. Key activities, outputs and milestones will be accompanied by timely communication activities.	The Outreach Plan will detail each communication and dissemination activity of the project and will assign clear responsibility to specific WP and partners. The Plan will be updated regularly during the implementation of the project.	The location of communication activities is also important. Target audiences should be reached wherever they are and at all relevant levels, from local end-users in the Climate Change Hotspots to EU policy-makers.

A **Dissemination and Communication** strategy will be fully developed in the early stages of the project (WP9). Focus on dissemination and communication activities in all WPs ensures that the full impact of the project is achieved. An online website will be complemented with a comprehensive program of dissemination activities to ensure the maximum engagement with public and private sector representatives of a full range of candidate end-users and uses both within the scientific community and beyond. Communication foresees a number of tools for the implementation of our strategy (see also next Section 2.2a). Suitably framed messages delivered through dedicated dissemination channels will help us in publicizing our work and in generating interest in the project and its outcomes. A particular focus will be on the dissemination of the CLINT results to benefit the Copernicus programme. Based on the successful and well-established dissemination and communication strategies of each project partner, we will be able to tailor our messages for a full range of potential end-users and uses working on distinct strategies that rely on targeted messages, means and language according to the identified communication targets.

Exploitation will involve the development of suitable exploitation options within WP9, combined with a pro-active innovation management approach. CLINT exploitation strategy is based on two different lines:

- **Individual exploitation** by each consortium member according to the individual interests (see Table 2.3) that will be further developed as part of T9.4.
- **Joint exploitation:** the main routes for joint exploitation are the support provided to EU policies such as Destination Earth, Green Deal and Digital Strategy (WP6), the potential uptake of the outcomes of the CLINT project by the C3S (WP8), and the commercial exploitation of the AI-enhanced prototypes/demonstrators by TCDF as commercial CS according to the exploitation plan (WP9).

a) Dissemination and exploitation of results

The dissemination and exploitation of the project objectives and results are an integral part of the CLINT strategy to achieve its expected impacts, and they support a dialogue with the project stakeholders and target audiences rather than a unilateral distribution of information.

Scientific and technical results of CLINT will be made available to the public and disseminated regularly through project reports and technical documentation that will be available on the project website, along with publications in the scientific literature and conference proceedings. Dissemination and exploitation will be managed in WP9 and will use a number of dedicated instruments:

- **CLINT project website**: shortly after the project launch, the first version of the public website will go live. It will contain the main project information such as objectives, planned activities, links to related literature, organizations and projects, events and networks. The website will be constantly updated to showcase information on key project results and activities.
- **CLINT social media**: social media such as Twitter and/or LinkedIn will be used to communicate and disseminate project results particularly in the research, education and end-users' communities, with the aim of facilitating a direct communication of project-related activities to a wide external audience.
- **Conferences and workshops**: project results will be widely disseminated through publications, talks and posters at relevant international conferences as well as in dedicated workshops and webinars.
- **Webinars and/or summer school**: know-how transfer will be organized through a series of online course units to be delivered remotely either during the project duration or in a final summer school to be organized in the last year of the project.
- **Policy outreach:** another pillar of the CLINT dissemination will aim at presenting project results to selected public, private and academic institutions through dedicated workshops and policy briefs in order to support bottom-up EU policies and discuss the potential uptake of project's results and the remaining research gaps.
- **Demonstrator of AI-enhanced CS**: A prototype of AI-enhanced S2S forecast of heat waves/warm nights and extreme droughts will be set up and exploited during the last year of the project. The visualisation of the forecast will be freely accessible for project communications and general outreach.

Dissemination and exploitation within CLINT: This will be managed mostly in WP9, which will establish a technical and scientific collaboration platform comprising the main input and output data, and a source code repository with bug tracking system to facilitate distributed software development. The source code repository will allow partners to pull changes from the repository and merge them into local development branches, and to push contributions to the repository that will be revised and then added to the Master branch.

Dissemination and exploitation beyond CLINT: The outputs of CLINT will comprise reports, scientific publications, datasets and software. All project reports will be viewable and downloadable directly from the CLINT website. Publications, data and software will also be made available according to the EU open access policy:

- **Open access to peer-reviewed scientific publications**: Open access will be granted to all scientific publications resulting from CLINT with a combination of golden and green open access.
- **Open access to data**: The data compiled in the project will be wide-ranging and it is expected that most of the required data is publicly available. The output data generated by the project will also be made freely available (e.g., on Zenodo), with selected datasets that could be published in the CDS of the C3S.
- **Open Source Software:** A central repository of research code (or selection thereof) generated by WP2-7 with appropriate documentation will be made freely available on github. The WPS developed in WP8 will be maintained as part of the existing birdhouse github repo.

Each consortium member has defined individual strategic interests that will be further developed as part of T9.4 and in relation to the CLINT results. The exploitation plan will be developed mid-term in the project (MS24) and will be revisited and consolidated at the end of the project (M48, D9.3) to identify and refine the activities to be implemented beyond the lifetime of the project. The anticipated individual strategic exploitation interests by each partner are reported in Table 2.3.

Table 2.3: Individual strategic exploitation interests of the CLINT partners.

Partner	Interests
POLIMI	• Use of ML algorithm supporting CLINT AI-enhanced CS in future research • Establish partnership with COPERNICUS and Climate Informatics • Use of CLINT outcomes in research, training and academic programs
CMCC	• Use the AI-Enhanced EE detection indices for future CMCC research on EE • Propose the new AI-Enhanced EE indices to the Climate community (i.e. CMIP) as improved standard diagnostics • Extend the CLINT collaboration between Climate and AI communities through shared academic programs
HZG	• Extension of CLINT seasonal prediction algorithms to North European storm surges, to be offered to the German Federal Shipping and Hydrographic Office (BSH) • Establishment of a PhD course on ML and EE at the PhD school SICSS, University of Hamburg
CSIC	• Advice to AEMET (Spanish Meteorological Agency) in extremes attribution • Use of CLINT algorithms in research • Improve CS provided by the CSIC climate Technological Platform with CLINT outcomes
SMHI	• Act as knowledge purveyors and establish AI-enhanced activities across Copernicus (C3S and CEMS) and WMO CSs • Use of AI-based knowledge and ML-tools on SMHI's CS supporting European user needs in the water-related sectors • Communicate CLINT new knowledge and AI-enhanced CS to researchers, early career scientists, forecasters and water authorities
HKV	• Create opportunities for future consultancy or research assignments for HKV by the stakeholders or other interested organizations in the Dutch water sector • Improve HKV connections to the (inter)national (research) community active in the field of AI and CS. This will provide HKV with the opportunity for future cooperation and to stay up-to-date about the latest research developments in the field • Expand HKV expertise by learning from work done in cooperation with CLINT project partners, specifically, on tropical cyclones and AI for drought management
E3M	• Develop the PRIMES modules further by expanding the capacity to model the effect of extreme events on the energy system • Establish partnerships with institutes dealing with extreme event forecasting • Use the improved PRIMES modules to provide consulting services to policy makers and private companies.

TCDF	• Improve the skill of EE detection in our commercial S2S forecast service and • Integrate in our offer and exploit the AI-Enhanced CS prototypes in S2S and climate projections products • Promote the new services to the climate change adaptation and disaster risk management community • Expand technical and commercial synergies with CLINT partners
DKRZ	• Integrate and promote open source CLINT web processing services as part of the Birdhouse open source community effort • Evolve and demonstrate service integrations with Copernicus as well as the EOSC • Use CLINT WP8 outcomes in training activities (targeting the climate impact research community)
IHE	• Findings on how to develop AI-enhanced forecasts and climate projections for extreme events, will be taken up, together with consortium partners, in follow-up applied research projects for potential end user organisations in NL and in the Global South (e.g. Africa) where IHE has a strong network in the water sector • AI algorithms developed, and methods for combining with forecasts and projections for extreme events, will be taken up in the MSc curricula at IHE • Resulting CS for the local case studies, and the increased understanding on how to develop such services tailored for relevance to case study end users, will be taken up in IHE MSc curricula. • Next to regular MSc programmes, IHE is actively involved in institutional capacity development programmes and projects with partners in the Global South, e.g. through tailor-made-training and short courses (face-to-face and online), for which disaster risk reduction of extreme events is of immediate interest
ECMWF	• Prepare the integration of AI-enhanced activities into Copernicus (C3S, CAMS and CEMS) services and WMO CSs • Produce world leading forecasts of heat waves, warm nights and Tropical Cyclones • Reducing loss of live, economic and social impact of heat waves, warm nights and Tropical Cyclones by providing products of earlier warnings to National Hydrometeorological Services, EC and EU Agencies, NGOs and other relevant entities • Support economic growth of weather relevant and sensitive European industry
UAH	• Use of CLINT outcomes in EE detection to alternative phenomena description. • Use CLINT ML algorithms in alternative research fields. • Extend the CLINT collaboration between Climate and ML communities through research networks and programs.
JLU	• Use of CLINT AI-enhanced approaches to the agronomic communities • Integration of CLINT outcome into the agricultural monitoring and seasonal forecasting system of the European Commission in support of the new CAP • Explore the use of CLINT AI-enhanced outcome in the agricultural impact assessment community, e.g. within AgMIP
OGC	• Deployment of CSIS components in C3S and other EU data processing infrastructures to be used by a large audience of scientific and semi-scientific users

	• Use of CLINT findings for international consultation regarding options for ML usage in climate actions to achieve the targets of the international political frameworks primarily the Agenda2030, Paris Agreement and Sendai Framework • Use of CSIS components to effectively produce high level climate information tailored on demand of the clients to enrich their climate service consultation.
UCM	• Apply CLINT AI-enhanced CS to drought management needs • Transfer CLINT outcomes to professional training and academic programs • Adapt CLINT outcomes to support decision-makers in EE management

Knowledge management and Intellectual Property Rights (IPR) will be addressed in full compliance with the rules identified by the EU. To this aim, a detailed description of the Intellectual Property Rights agreement (IPR) is part of the Consortium Agreement.

b) Communication activities

Defining the target audience is important to produce impact outside the CLINT consortium. The formats, language and focus of the communication activities will be shaped according to the identified communication targets (see Table 2.3). The following audiences have been preliminary identified:

- The first audience are the **CLINT end-users** including both decision- and policy-makers at the European level and in the local Climate Change Hotspots, which are potentially direct beneficiaries of the project outcomes from WP6 and WP7. These WP will design a supervised co-creation strategy to organize the interaction with this group.
- The second category comprises **potential users**, such as Copernicus users, ECMWF member states, and international committees, which will benefit from the WPS developed in WP8 and the publication of open data and code.
- The third category is the **scientific community**, which will allow sharing high-quality scientific results at the national and international level.
- The fourth category is **climate change disaster risk managers** and **adaptation practitioners** that need access to forecasted and projected EE assessments that will be engaged through the demonstrator and project communications around it.
- The last audience includes the **general public** and the **civil society**, with a non-scientific background, which will be engaged though the project website and the social media to create a virtual community around the project.

Table 2.4: Overview of CLINT communication targets and tools.

Target audience	Goal	Communication tools
CLINT end-users	Generate a bi-directional dialogue for the co-development of the AI-enhanced Climate Services	• Face to face meetings • CLINT website • Policy briefs
Industry and policy-makers	Maximize the uptake of project results by experts and practitioners	• Face to face meetings • CLINT website • Conferences and workshops • Demonstrator and other examples

Scientific community	Create formal and informal networks for sharing the project results	• Scientific publications • Conferences and workshops • CLINT website
General public and civil society	Establish an effective communication for promoting the project findings to a wide virtual community	• CLINT website • Demonstrator • Social media • Press releases

3. Implementation

3.1 Work plan

CLINT is structured in nine WP as reported in Table 3.1a and illustrated in Figure 4. The timing of the different WPs with the associated deliverables is shown in the GANTT chart in Figure 5. The full list of deliverables is reported in Table 3.1c.

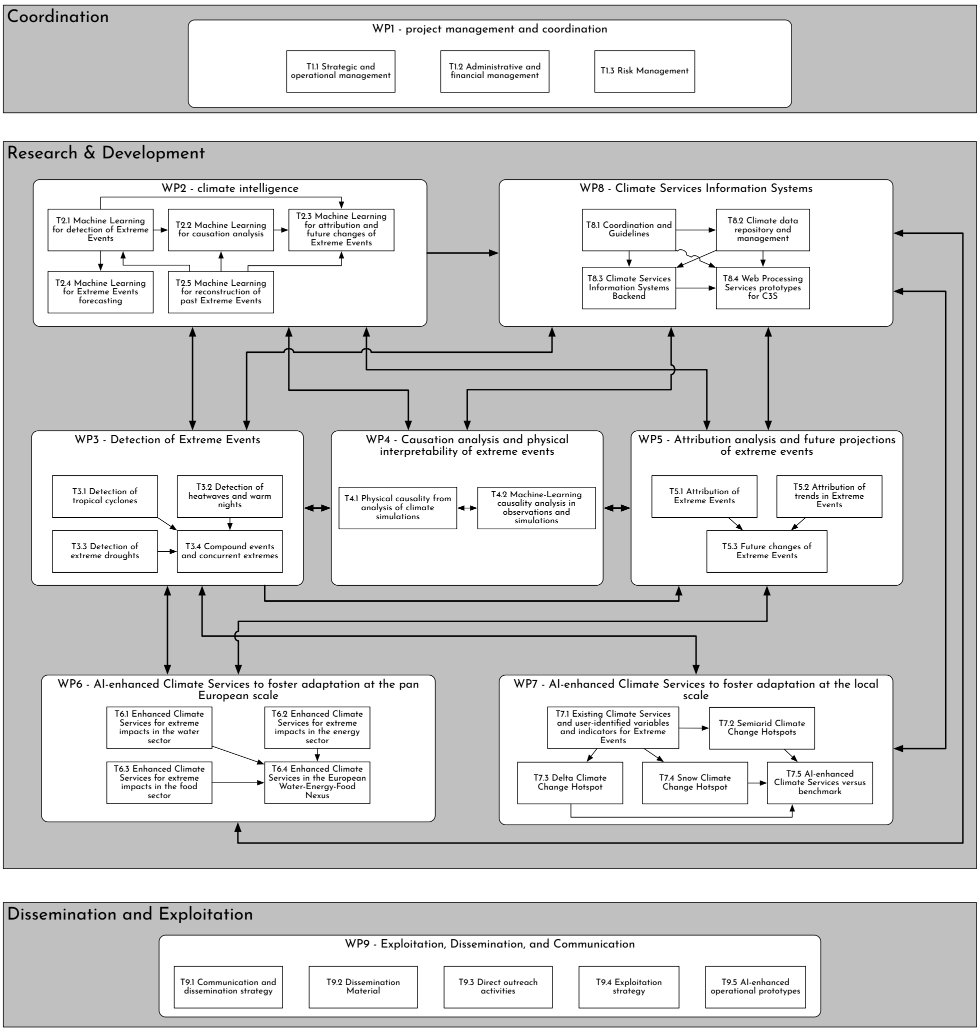

Figure 4: CLINT Pert chart.

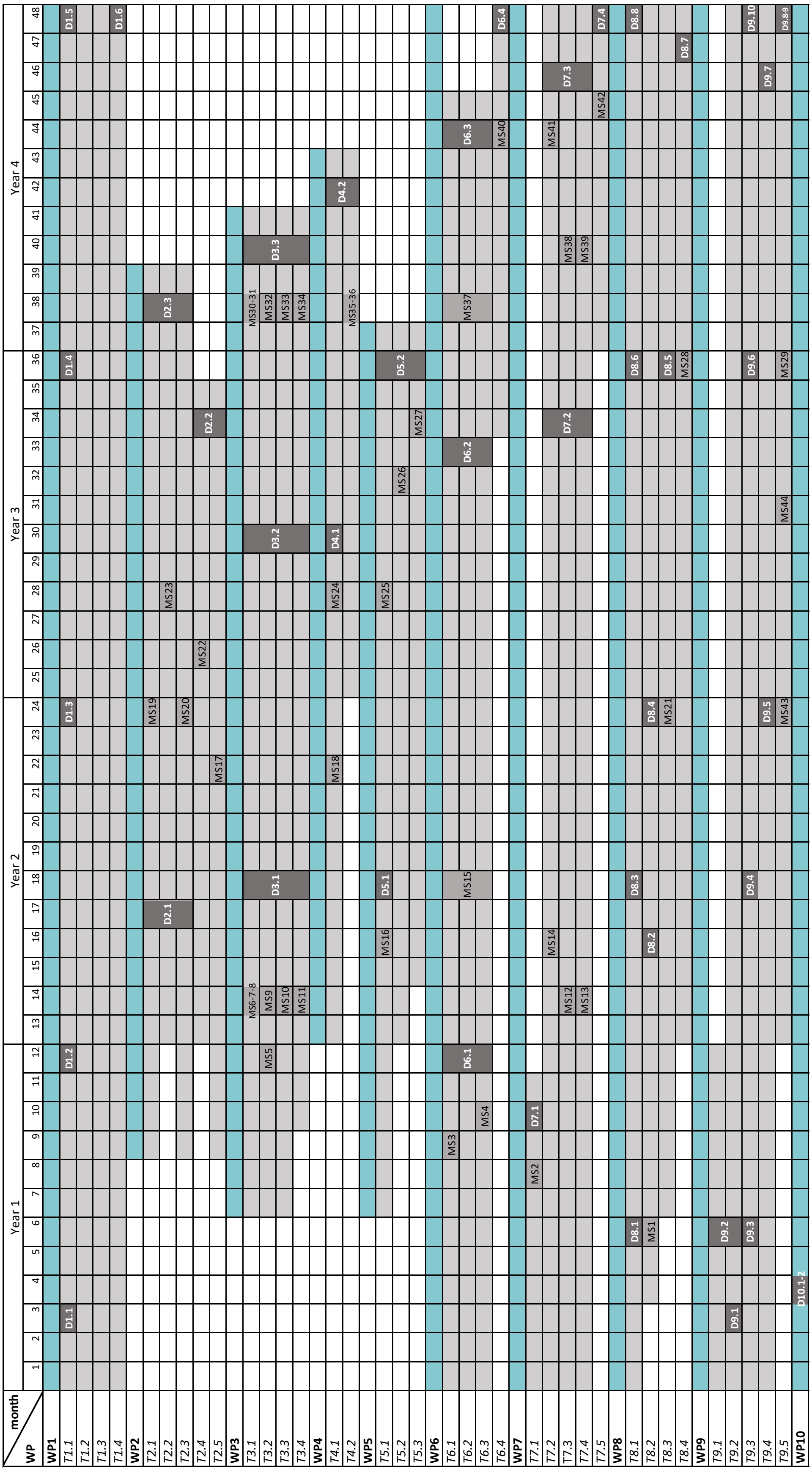

Figure 5: CLINT Gantt chart

3.2 Management structure and procedures

3.2.1 Project Organisation

CLINT has been designed to ensure a coherent scientific, administrative and financial coordination of the whole consortium and all related activities, as well as to provide all the participants with the support and tools required for the achievement of the project objectives. The efficiency of the project management and coordination will be ensured using a sound organisational structure, clearly assigning responsibilities to the different participants of the project. This organisational structure will be supported by project management methods relying on the latest communication and collaboration technologies. Figure 6 reports the adopted management structure. The planned structures and roles are described in detail below.

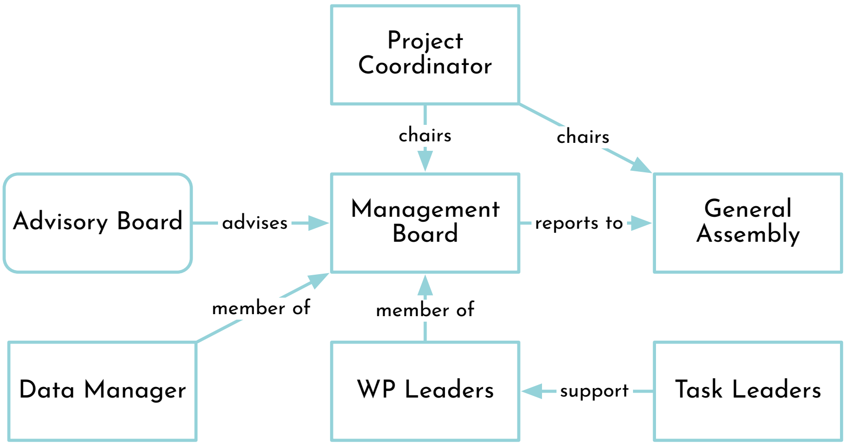

Figure 6: CLINT management structure.

The **General Assembly** (GA) is composed of one representative per partner and chaired by the Project Coordinator. In normal circumstances, it is only expected to meet annually. Decisions within the GA will be taken upon 2/3 majority, each partner having one vote, with the coordinator having a casting vote if necessary. The GA will be responsible for monitoring of project progress and costs; the preparation of any contractual changes and revision of the project plan in response to unforeseen problems; and, finally, contribution to the resolution of disagreements between participants and conflict resolution.

The **Management Board** (MB) will be the supervisory body ensuring successful execution of the project, and will be accountable to the GA. The board will be chaired by the Project Coordinator and composed by WP Leaders along with the Data Manager. The MB will convene monthly through online and/or physical meetings. MB meetings will be chaired by the Project Coordinator. MB will be in charge of preparing the WP activities, budget and effort allocations; approving and releasing deliverables; approving the content and release of press articles and joint publications; deciding on protection and access rights to knowledge based upon the Consortium Agreement; arbitrating on deadlock situations and addressing financial and administrative issues.

The **Advisory Board** (AB) will consist of a mixture of high-level researchers and academics, and stakeholders and organizations active in the research domain. It will advise the MB on the central scientific scope and direction of CLINT, and on research design issues, taking account of new scientific developments and insights. Approved members will be appointed either for the duration of the Project or for the duration of a specific task assigned to the AB. Meetings of the AB will be linked to General Project Meetings. The main tasks of the AB are supervising quality and coherence of the research achievements, ensuring coordination between programmes and initiatives at the EU level, ensuring an impact and exploitation of the results. The AB members will be selected at the Kick-Off meeting.

The **Project Coordinator** (PC) is responsible for the scientific and technical as well as the administrative management, reflected by the WP1 structure and tasks. In a consortium of this size and ambitious work plan, the PC secures the most efficient and seamless management. The role of the PC is defined in the Rules for Participation and the Grant Agreement. The CLINT PC will be Prof. Andrea Castelletti.

The **WP Leaders:** In addition to the usual role like any partner, WP Leaders will translate decisions of the MB to management tasks, and organize meetings with WP participants, when required. Regular teleconferences within/between the WP will take place and physical meetings of WP teams will take place as side-events during the General Project meetings held annually. WP Leaders will be responsible for management and technical coordination of their WP, sharing information (deliverables, progress, statement of expenditure) with the MB, taking decisions on technical methods, models and tools to be used, representing the consortium at conferences, workshops and dissemination events related to the WP, coordinating WP tasks/activities and ensure effective communication among participants as well as supervising and assessing progress against objectives according to the factual and verifiable **project milestones** listed in Table 3.2a. The WP Leaders of CLINT will be selected during the Kick-Off meeting of the project based on their qualification to accomplish the objectives of the assigned WP and their strategic interest in the output or content of the particular WP. Co-leaders will be also appointed to support WP leaders. In addition, a **Data Manager** will also be selected to ensure an efficient management of input/output data across WPs.

The **Task Leaders** support the WP leaders and are the managers in charge of each Task and their responsibilities are the scientific co-ordination and supervision of the work related to their assigned Task, including the organisation of work by some or all of the participants in the Task, review of the results of the work carried out in each Task, confirming the suitability of the next stages in the project plan and identifying possible problems, and finally ensure the timely delivery of agreed deliverables to high standards. The Task Leaders (organisations) have already been appointed and are clearly stated in the WP description.

3.2.2 Project management procedures

Project management activities will be based on the following procedures, which will be agreed among project partners and detailed in the Project Management Plan (D1.1): i) Consortium Agreement; ii) Project monitoring and control process; iii) Project deliverables reviews and validation; iv) Conflict Resolution procedures; v) Risk management.

Consortium Agreement

The Consortium Agreement (CA) defines and completes any points not covered by the EC Grant Agreement. The CA has been signed by all the partners and is based on the DESCA model. The CA includes in particular details about:

- The organisation of the consortium, as described above
- The financial distribution: the consortium agreed on distributing the Community Financial Contribution on the basis of each participant's effort and activity type
- Procedures for changes in the consortium composition
- IPR and exploitation: definition of the background brought by all participants and related access
- Rights, rules for joint ownership, access rights to project results for participants and 3rd parties

- Dissemination: rules for managing confidentiality and approving public presentations and publications.

Project monitoring and control process

Project monitoring and control processes allow for the planning, tracing and monitoring of work progress and other events that impact the project. The main formal occasions for project control will be:

- **Management Board meetings** scheduled both regularly (on a monthly basis) and for special purposes and held remotely.
- **Work Package meetings** organized by WP leaders on a regular basis or when needed and generally held remotely.
- **General Assembly meetings** will normally be planned to correspond with project plenary meetings or on request of either the Project Coordinator or project partners.
- **Project Plenary meetings** will be organized once per year starting with the kick-off meeting and will be host by selected partners.

Project deliverables reviews and validation

Accurate review and quality check of milestones and deliverables will be insured by a clear and transparent submission and reviewing process. Two reviewers will be appointed per deliverable, with the goal of both validating scientifically the deliverable content and checking its formal quality. Reviewers will be selected among the partners not involved in the deliverable preparation. The full list of reviewers will be included in D1.1. Deliverable will be submitted to internal review one month before the EU submission deadline. Reviewers will accomplish their task in two weeks and the WP leader and Project Coordinator will perform a final review on the revised deliverable prior to submission.

Conflict Resolution Procedures

Each WP will be expected to follow the instructions of the overall CLINT coordinating tasks. Within a WP, the internal management will attempt to resolve any conflicts. The WP leader may call upon the appropriate MB Director for assistance. Concerning conflicts between WP, it is expected that first attempts will be to solve any problems bilaterally. In the exceptional case that conflicts cannot be solved at a WP level, the MB may be called upon by the respective WP leaders and asked to solve the conflict. The MB will be in charge of ensuring that all pending conflicts are resolved within reasonable time frames. In very serious cases, for example when a decision is appealed to the GA. The GA decision is then final and binding on all management bodies.

Risk management

In a project of this complexity, risk management and contingency planning is important to ensure that the project strategy, operations, outcomes, and budget remain on track. Risks will be mitigated by the Management Board to prevent any deviation from the plans. To this end, a comprehensive risk management process and risk register will be implemented over the duration of the project. WP leaders will present an assessment of progress, and risks to progress at the MB meetings and propose contingency plans where necessary to address any specific identified risks. The general types of risks, examples for specific risks and their mitigation covered in the risk management process are summarized in Table 3.2b.