IS-ENES3 Milestone M3.1

Report on user requirements

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Abstract:
This report gives an overview of the information on user requirements collected until June 2020 (first 18 months of the project). It is part of the work done under Task 4 in WP3-NA3. In order to work on widening the user base, nurturing existing users/stakeholder communities, improving mutual understanding between users and developers and expanding community standards) information on user requirements for the various services and tools developed by IS-ENES3 are needed. This report also described the various user groups that this project focuses on and the methods used to collect information on user requirements related to data, models and tools. Collection of information on user requirements will continue afterwards and at the end of the project a complete overview will be given in D3.6.

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1. Objectives

WP3/NA2 aims at further engaging with the community of users of IS-ENES services. This is done through widening the user base through training, engaging the community in co-constructing standards and expressing needs, and engaging the younger generation in interdisciplinary approaches. Target users will be the climate researchers and the Vulnerability, Impacts and Adaptation (VIA) researchers. WP3/NA2 also targets societal innovation through the emerging climate service providers.

In order to work on the objectives of the work package WP3-NA2 (widening user base, nurturing existing users/stakeholder community, improving mutual understanding between users and developers and expanding community standards) information on user requirements for the various services and tools developed by IS-ENES3 are needed. When the services and tools meet the requirements in a better way, they will be used more widely. Therefore, collection of user requirements, both scientific and technical, is an important task in this project.

This report gives an overview of the information on user requirements collected until June 2020 (first 18 months of the project). It is part of the work done under Task 4 in WP3-NA3. Information on the user requirements related to data, models and tools is collected. Collection of information on user requirements will continue afterwards and at the end of the project a complete overview will be given in D3.6 (month 46). WP3/NA2 ensures exchange of user feedback and requirements with the other WP's (WP5/NA4, WP7/VA2, WP8/JRA1, WP9/JRA2, WP10/JRA3).

The set-up of the WPs and tasks is based largely on known requirements for the climate research infrastructure. This report will focus on additional information and new insights in user requirements related to climate data, climate models and tools.

2. Methodology and Results

2.1 Description of the potential users of the results of IS-ENES3

The potential user groups of the services and tools of the IS-ENES3 project are very diverse and not every group is interested in all services and tools provided. To keep the requirements of all these users in mind, we first give a short overview of the potential users we have in mind (based also on the groups identified in the CLIPC project (Bennett & Groot, 2015). It is important to distinguish between different user categories as each has its own requirements and preferences and they may need different forms and levels of guidance (CLIPC, 2016).

Climate scientists (including students)

- Climate modelers work on the improvement of climate models. They need among others tools to exchange data between modules, to evaluate or calibrate models with observational data, or against other models, etc. They also design and make specific climate model simulations, following common protocols that can be used for climate services.
- Climate scientists analyzing climate (model) data need tools to select data, to process data, to visualize climate data, to download large amounts of climate data, to evaluate climate model data (determine skill/bias), etc. Flexibility with many choices in examining the data is key from these climate scientists' point of view. They probably also wish opportunities to easily share data files. Key for them are clear conventions on data file formats, naming of climate data and indices, together with complete documentation and provenance information. Regularly, results from the analysis are used for climate services, e.g. climate scenarios, analysis of the change in global temperature under specific SSP-RCPs.

Vulnerability, impacts and adaptation (VIA[1]) researchers (including students)

- This is a very broad group of users from many different sectors/disciplines who will use climate data directly for VIA studies.
- As with climate scientists there are VIA-researchers that focus more on the development of models (impacts, to test various adaptation measures, etc.). These researchers may rather use observational climate data or reanalysis to calibrate their models. Others focus more on the analysis of vulnerability, impacts and adaptation measures. These researchers are more likely to use data from climate models to calculate vulnerability, impact and adaptation options under future climate change. Climate data are often used as input for such models. The spatial and temporal resolution, the domain, the format, etc. may differ a lot between

[1] For types of VIA see Hinkel et al. (2012)

the various disciplines, but also within. They need tools to select data, to process data, to visualize climate data to download large amounts of climate data, to evaluate climate model data (determine skill/bias), etc. These impact scientists benefit from partly preprocessed data and indices (e.g. bias-corrected). They need clear conventions on data file formats, naming of climate data variables and indices, documentation and provenance, etc.

- The level of background knowledge on climate data differs a lot between the various sectors/disciplines. In general researchers on water management are more used to work with climate data than users from e.g. financial/economic research who will need more guidance for the use and selection of climate data.
- These groups use climate data and information, but they also often serve as climate service providers further in the chain.

Climate service providers (or intermediaries; Bennett & Groot, 2015)

- Very diverse group, but IS-ENES3 focuses only on those climate services providers that use climate model data directly.
- As mentioned above, institutes for climate research often also provide themselves climate services to society. This can be in the form of climate data that others can use (e.g. for vulnerability and impact assessments), information on the state of the current climate and what can happen in the future (e.g. climate scenarios), information on what the impact of mitigation measures can be on the future climate, etc.
- As mentioned above, institutes for VIA research often also provide some climate services to society. This can be in the form of data and information on the impacts of climate change and vulnerability in many different sectors. This can also include risk analysis and options to adapt to climate change.
- Commercial climate services providers often use the basic data from e.g. climate research and VIA research. They process the data into products that are tailored to specific user groups. They profit from preprocessed datasets and tools to process climate data into tailored data sets. Commercial providers may also help with decision support related to mitigation and adaptation to climate change (e.g. consultancy companies). Then the provision of climate services is an element of their wider services. IS-ENES3 does not develop services for this.
- Governmental organisations at different levels (national, regional, municipal, etc.) may also serve as climate service provider. They often use information from research institutes (may also be governmental organisations) or commercial providers.
- NGO's may also serve as climate service provider. They often use information from research institutes or commercial providers, sometimes with their specific expertise or data added.
- All climate service providers benefit from clear conventions on data file formats, naming of climate data and indices, documentation and provenance, etc.

- Providers that use climate data will need tools to select data, to process data, to visualize climate data, to download large amounts of climate data, to evaluate climate model data (determine skill/bias), etc.

Other potential user groups

- Companies such as reinsurance companies, may use the basic/raw climate data themselves to process them into the information that they require (they are their own climate service provider). They may need tools to select data, to process data, to visualize climate data, to download large amounts of climate data, to evaluate climate model data (determine skill/bias), etc. although they may have developed their own tools. They also need clear conventions on data file formats, naming of climate variables and indices, documentation and provenance, etc.
- Other societal users (or societal end users; Bennett & Groot, 2015): everyone interested and able to use climate data. This could be an NGO that wants to create more awareness of climate change impacts. The expectation is that most of these users may use the Climate4Impact portal and no other tools of IS-ENES3. Some may find the C3S CDS and Toolbox more adequate / helpful.
- New users from interdisciplinary research fields, attracted by inclusion of climate data in interdisciplinary search catalogs e.g. in the b2find catalog in the context of the EOSC[2].

For most of these users it is important that they can get access to the most up-to-date information through tools that work easily and that will continue to exist for many years.

[2] https://www.eosc-hub.eu/services/B2FIND.

2.2 Description of the results of the IS-ENES3 projects and link with user groups

As indicated in paragraph 2.1 not all user groups are interested in all tools and services provided. We shortly list the tools and services provided within the IS-ENES3 project. The services mentioned under Models and tools will be used especially by climate modelers and some also by other climate scientists. The services and tools mentioned under data and tools are for all users, although some will be used more by specific groups.

Tools for data access and use

- Indices and indicators
- Derived data: climate model evaluation data products based on the ESMValTool
- Metadata/documentation requirements
    - ES-DOC services (for data users; also other projects/types of datasets)
    - Indices and derived data
- Standards (including Climate and Forecast Convention)
- ENES CDI data distribution (ESGF) data archival (WDCC)
- CDO data post-processing (climate data operators; for analyzing gridded data)
- Transnational access mechanism (TNA) and VA access to compute resources
- Climate4Impact portal (including access to other types of data sets, especially VIA-researchers and CS providers)

Tools for models access and use

- Unified NEMO sea ice model
- Standards
    - Common standards for European data sharing, scientific provenance of model evaluation
    - Framework for coding standards and improving code efficiency (exploit option of ML and AI)
- ESM services (HadGEM/UKESM, EC-Earth, NorESM, NEMO): Regular updates, Documentation and Issue tracking
- Infrastructure tools
    - OASIS3-MCT coupler (synchronized exchanges of information between different components of the climate system in climate models)
    - XIOS (data flow infrastructure for climate models)
    - Cylc/Rose (for cycling workflows)
    - ESMValTool (model evaluation)

2.3 Methods used for collecting information on user requirements

2.3.1 Delimitation

As indicated in the section on the objectives, the set-up of the work packages and tasks in IS-ENES3 is based largely on known requirements for the climate research infrastructure. In this report we will not repeat all these specific requirements, but we will focus especially on new insights on user requirements.

Known user requirements included in the set-up of the project can be summarized with:

- Unification/standardization, consistency, interoperability, compatibility (with different programming languages and different configurations)
- Scalable, modular and containerization, easy to extend
- Technically robust and reliable/secure
- Easy to maintain
- Efficient/fast/work smoothly/problems solved fast
- Up-to-date (data; coding and design standards; technologies)
- Sustainable (will continue to exist)
- Flexible
- Transparency, provenance, reproducibility
- User friendly, usable
- Quality

Several of these requirements are mentioned also in Milestone 10.1 (Fiore et al., 2020) on technical requirements on the software stack.

In general, the requirements focusing on users of data and tools aim at making data, models and tools easier to find, easier to use and interpret correctly and to widen the use of them. If these requirements are not met, users may start looking for alternative services and tools.

In this document user wishes and requirements are listed, but no judgment is made whether all wishes/requirements can or should be implemented. Some require a lot of work and can only be taken into account in the long run. Some of the data and tools are for a large range of users, and it is difficult to include all user wishes/requirements at the same time or in the same tool. In some cases, however, more elaborate guidance material could substantially help less experienced users or users with less background knowledge on climate data and modelling (especially in the case of the Climate4Impact portal).

2.3.2 Methods and sources

The following methods and sources are used for collecting information on user requirements. At this stage, not all are used for this report. However, they will be used later on.

- During WP3 tasks 1, 2, 3 and other interactions with users in other WPs (e.g. access activities) feedback are collected (e.g. working with the C4I portal in tasks 1 and 2 provides indirect information about requirements, challenges and questions from various user groups).
- Literature review and other desk research: reports and articles that report on challenges and requirements in other projects (e.g. IS-ENES2, CLIPC, ERA4CS, WCRP/CMIP, Copernicus climate Change Service).
- Feedback and questions from (potential) users of the tools and services during e.g. short trainings, demonstrations or in webinars and during the schools that will be organized in IS-ENES3 (e.g. feedback on the C4I portal).
- Survey/questionnaires among (potential) users of the IS-ENES3 tools and services
- Interviews with and feedback from representatives from e.g. Young Earth Science Scientists, ISIMIP community for VIA research (contact with Q. Lejeune and I. Menke), Climate-KIC for climate services industry, etc. Where needed, targeted interviews will help refine the technical and services requirements
- Information from other WPs (workshops, reports)

2.4 Results: User requirements per type of service

2.4.1 Services related to tools for data access and use

2.4.1.1. Indices and indicators

Several lists of indices were developed by WMO, WCRP Expert Teams (ETCCDI and ET-SCI), as well as European initiatives (ECA&D) and more recently EU Horizon 2020 projects and Copernicus C3S activities. These indices were selected, since they are seen as core climate indices or because they are widely used for specific sectors or applications. Within this project a workshop will be organized to see whether in Eastern Europe there are other additional indices required. This information will become available later.

CLIPC makes a distinction between different impact indicators. The tier 1 indicators give information on aspects of the past and future climate that link with impacts to nature or society. Tier 2 indicators give information on the physical impacts of climate and climate change and are determined using climate data (Costa et a., 2015). These Tier 2 indicators require additional non-climatic data sets or impact models. The IMPACT2C atlas also shows several of these Tier 1 and 2 indicators, just as the European Environmental Agency indicator site (EEA, 2016).

As part of WP3-NA2 (task 3) an overview is made of the most important lists of climate indices together with their metadata. If more climate indices or tools are developed within the Climate4Impact portal to calculate climate indices, the following would be interesting:

- Related to climate change it would be interesting to have information on changes or trends in climate variables. This information was provided through the website of ECA&D and valued a lot by several users
- Many climate indices in the lists mentioned above are based on one climate variable, but in practice indices based on a combination of several climate variables are regularly used. E.g. for agriculture and ecosystems climate indices that combine information about temperature and precipitation are often relevant to either indicate good growing conditions or conditions that could cause damage. Some combined indices are included in the list of indices and are evaluated in the ESMValTool (https://esmvaltool.readthedocs.io/en/latest/recipes/recipe_combined_climate_extreme_index.html), but it would be interesting to find out if more are needed by particular groups of impact researchers or climate service providers.
- Although many users indicate that information about uncertainties (and uncertainty propagation) is important (e.g. Scanlon et al., 2015), information about natural variability (year-to year and 30-year to 30-year periods) or errors is not always available for indices. On the ECA&D website information was given on whether changes were significant or not. Also, probability ranges for indices would be useful.

- Most indices are now calculated per year or per season. For many applications/sectors it would be interesting to have the possibility to calculate indices for other periods in the year and with varying length.
- It could also be interesting to have climate indices that are combined with non-climate variables, such as some used in the CLIPC portal (e.g. potential impact of flooding on major roads) or in the C3S SISs
- The diversity of users and approaches and the different levels of community organisation complicate the identification of such indices or may lead to a large number of closely related ones. A duplication and gap analysis may be needed, with the help of users.

2.4.1.2. Derived data: climate model evaluation data products based on the ESMValTool

As a result of the ESMValTool a lot of climate model evaluation data can become available which is useful for climate modelers to evaluate the climate models. However, other groups of climate data users may profit also from the information that the ESMValTool can provide.

The information can be used for example for two other purposes:

- For bias adjustment of climate model data
  - Since many climate impact modelers/scientists are interested especially in extremes, a bias adjustment that takes into account only the average or median bias is not suitable for most of them. The bias can be different for averages than for extremes, this should be taken into account during the bias correction. An approach that could work well is using percentiles (e.g. 5%, 10%, 25%, 50%, 75%, 90% and 95%). Such an approach is also used for the bias-adjustment of the EURO-CORDEX runs. Several of these are available through the ESMValTool (https://esmvaltool.readthedocs.io/en/latest/recipes/recipe_extreme_events.html; https://esmvaltool.readthedocs.io/en/latest/recipes/recipe_quantilebias.html)
  - The bias can also change throughout the year. Therefore, it is advisable to determine the biases per season, or even better per calendar month (for smoother change in bias throughout the year)
  - Biases can be determined against different types of data sets, e.g. re-analysis such as ERA5 or datasets based on observations such as E-OBS. Especially for precipitation this is important since area-average data have much more rainfall days than point data and the extremes in area-average precipitation are smoothed compared to “point” data (from measuring stations). Some impact researchers use especially point data (e.g. for simulating agricultural production) and others area-average data (e.g. for river discharge). The impact models are calibrated either with point or area-average data.

- For selection of climate model runs for climate model analysis or for impact analysis
  - Many impact researchers do not have the time and finances to use a large ensemble of climate model runs for their impact analysis. To get an idea of the range of impacts of climate change it also suffices to use a small number of climate model runs. In case a system is only sensitive to annual temperature, one can select a run with a high change and one with a low change of annual temperature, preferably both with a low bias. However, the information on the biases and changes in individual climate models under various RCPs is not that easily available until now. Within C3S a pilot for something similar was started (DCEM), but this only showed seasonal average biases and changes for temperature and precipitation. It is planned already to make the information from the ESMValTool available through the Climate4Impact portal, but it would be good to look at which climate variables are used especially to make a selection of climate models and how this information can be made available in such a way that it can be used easily.

2.4.1.3. Access to other (types of) data sets

Impact researchers often use high spatial resolution climate data for the past and future climate. Therefore, the observational data, reanalysis data and (EURO-)CORDEX data available are very helpful, especially for a large part of this user group. Many of these datasets are available already through the Climate4Impact portal. As many impact models are calibrated with observational data and since these models often contain non-linear relations, bias-adjustment has to take place before the climate model data can be used in these impact models. Many of these impact researchers have limited knowledge on how to perform a bias adjustment. Bias-adjusted EURO-CORDEX runs save them a lot of work (many available through the Climate4Impact portal). The same would be true if bias-adjusted datasets would be available for other CORDEX datasets and global ESM data (the type of bias-adjustment is important!). If no bias-adjusted climate model runs are available, detailed information on biases (from the ESMValTool) would be very useful for those who have to perform a bias-adjustment.

As indicated under “Indices” it would be interesting sometimes to combine climate variables with non-atmospheric climate variables (e.g. land cover or leaf area index (Hall, 2019), or to determine impacts, and vulnerability (UNEP, 2013; EEA, 2017)). Carter and Makinen (2011) compiled several publications with indicators and composite indices of vulnerability and the sectoral information systems of C3S also combine climate information with other variables to calculate impacts of climate change. This combination with other non-climate variables was also done within the CLIPC-project. In principle other types of datasets can also be provided through ESGF (e.g. ISIMIP data on impacts are also available). It is expected that especially impact researchers and climate service providers will be interested in combining climate data with other types of data. At

the moment we don't have a clear view on the most important types of data sets they are of interest (besides impact data sets and land use) and whether it is preferred to make them also available through the ENES-infrastructure.

2.4.1.4. Meta data /provenance

- **ES-DOC services**

The ES-DOC services for climate model data are very useful for a large range of users. However, it is not easy for users with little climate model literacy to understand the impact of the model building blocks on the usability or interpretation of the climate model results. Although probably beyond the aim of ES-DOC, users outside climate science could particularly benefit from some more guidance. The ES-DOC errata service providing "known issues" may help these users (such as done for ERA5 data: https://confluence.ecmwf.int/display/CKB/ERA5%3A+data+documentation#ERA5:datadocumentation-Knownissues). Although it is not possible to indicate the usability or fitness-for-purpose for all kind of users ((Nightingale et al., 2019; 2018), this information could help the users. These systems may not however replace the much necessary direct interaction between users and model data providers to collectively define the fitness-for-purpose, which very much depends on the science questions addressed.
Many users also like to have information about evaluation, quality and uncertainties of the data (Nightingale et al., 2019; 2018; Bessembinder, 2015). It would be useful to have a link to model evaluation results (e.g. with the ESMValTool) under this documentation (logical place to look for this information for a considerable part of the users).

- **Indices and derived data**

For climate indices and derived data, it would be useful to have similar documentation as for climate model data, that is also accessible in a similar way as e.g. the ES-DOC information in the Climate4Impact portal (METACLIP). For this it is probably easier to have the metadata stored in a separate file and a link to this in the data file. Interactive traceability chains are a useful and efficient tool for data users to obtain confidence in the quality, robustness, and limitations of data (Buizza, 2106). Different types of users may look for partly different meta information. Well-structured metadata will make it easier for users to find the information that is relevant for them.
Users don't always realize that indices that appear the same may be calculated in a slightly different way (e.g. different threshold temperatures 17 or 18 ºC may be used for "heating degree days", or different definitions for "growing season length") or that different dimensions are used. Well-documented metadata for all used climate variables, indices and other derived data will help users as well as data producers to avoid confusion and strange jumps or trends in data.For the activity on metadata for indices, an overview of methods used and dimensions is made and a climate index

metadata standard will be proposed, using as much as possible CF conventions or proposing extensions (WP3, Task 3)..
Also for indices and other derived data it is useful to have information on quality and uncertainties. The metadata for uncertainties across datasets is not consistent (Petri et al., 2016) or missing.

2.4.1.5. Vocabularies and standards for data

Common data format and a common convention for data records and exchange can boost climate services and the use of climate data. It reduces effort and costs for data management (Hamaker et al., 2017). On the 9-11th of June 2020 a workshop was held on many aspects of CF conventions. Here only some preliminary results related to names of climate variables are included.

- **Names of climate variables and indices**
  (http://cfconventions.org/Data/cf-standard-names/72/build/cf-standard-name-table.html)

To make it easier for users to find climate variables, climate indices and derived data, it is important that it is clear what the name and abbreviation of the variable, index or derived variable are and how they are defined. Especially for new users the abbreviations used are often difficult (e.g. Tas and Tg or Tmean) to recognize or they don't realize that indices that appear the same may be calculated in a slightly different way (e.g. different threshold temperatures 17 or 18 ºC, may be used for heating degree days). Consistent naming may help (CF-conventions) as well as a good overview of metadata of all used climate variables, indices and other derived data. For the activity on metadata for indices, a list of often used abbreviations for several climate variables is made).
For the INDECIS-project (Integrated approach for the development across Europe of user oriented climate indicators for GFCS high-priority sectors; http://www.indecis.eu/) indices are collected and defined for : agriculture, disaster risk reduction, energy, health, water and tourism. Many of these indices are the same as those used WP3-task 3, but some others are mentioned and some seem to have different acronyms, which may cause confusion.
Sometimes different names, abbreviations and definitions may be used for climate variables, indices or derived data outside the climate community. It may be useful to make a compilation of the various names used or make the existing ones easier to find.
Names should be understandable by a wide range of users, avoiding too much jargon, but at the same time they should not be too long.
Uncertainty information is considered important by many users, but there are many different types of uncertainties, which are not always calculated together with the data sets (e.g. uncertainties related to socio-economic developments are determined with the help of climate model runs with different RCPs). Kehoe (2020) proposes a standard for the names of uncertainties in climate variables (mainly statistical, errors). However, this does not include all types of uncertainties.

- **Names of climate data files**

The standard names of climate data files are often difficult to understand for users with little background knowledge on climate data. An easily accessible and understandable overview of the meaning of the various components of the datafile names can help users to find the data files that they need.

2.4.1.6. ENES CDI data distribution (ESGF) data archival (WDCC)

Data discovery: https://portal.enes.org/data/data-metadata-service/data-discovery/search-and-download
Technical requirements for these services are described in Milestone M10.1 with the help of use cases. They will be updated later on. Documents describing the overall architecture of the ENES CDI Software stack will be released throughout the project (months 18, 24, 36, 48), using as a starting point the technical requirements for the software stack in Milestone M3.7 (Pagé et al., 2020).
Climate models can produce a large amount of data nowadays, but the storage capacity is not always in line with what users would like to have. In the PRIMAVERA project, users indicated that they would like to have hourly data for several climate variables, but storing these data for all runs was not possible.

2.4.1.7. CDO data post-processing

Contact person: Uwe Schulzweida
https://portal.enes.org/models/software-tools/cdo; https://code.mpimet.mpg.de/projects/cdo/wiki

- Availability of consistent, flexible, easy to use and performant data analysis framework

CDO is not only used by scientists with focus on climate, but also weather services (production + development), data services (like Copernicus for server-side processing), private companies that deal with weather/climate data (local weather prediction, shipping) and the military. CDO has a public website with a ticket system and forum. Users can submit their wishes and requests. There are regularly new requirements from the users. Most of them are implemented quickly. No list of remaining wishes is kept for further development.
In 2019, when more CMIP6 data became available, some new operators have been implemented for CMIP6 compliant processing and calculation of climate extremes indices (Wachsmann & Schupfner, 2019).

2.4.1.8. Transnational access mechanism (TNA) and VA access to compute services

Contact person: Martin Juckes
https://portal.enes.org/data/data-metadata-service/analysis-platforms
The report on the first round of TNA will become available in month 18 of this project (WP7, Task 3: D7.1). The TNA activity is very new. The main new insight is the difficulty in advertising to

new users beyond the established user communities. It would be good to advertise these services more widely among potential users, but also to make clearer how users could potentially profit from these services and offer some support in using these services (the abbreviation TNA does not mean anything to these potentially new users). Because of the large increase in scientific data volumes in all scientific domains, the need of compute services to enable data processing as close as possible to data storage are needed. This is also one of the ideas behind TNA.
The major challenge is to provide Compute Services that can be used properly by users having a large range of both technical and climate science knowledge, with a proper intuitive user interface. Guidance and help will be crucial to support this service, and also the functionalities that are provided. A basic layer of generic services laying the foundation of tailored services will be able to provide needed functionalities for users (Pagé et al., 2020). This new compute service will initially concentrate on the processing of climate evaluation diagnostics based on the ESMValTool as well as multi-model data analysis. However, as indicated above, combinating climate data with data from other domains may become more important (e.g. for climate change impact assessments). It would be very useful if the Compute services and related functionalities could also be used for data from other domains. However, this is a challenge since they often use different approaches and technologies.

2.4.1.9. Climate4Impact portal

Contact person: Wim Som de Cerff/Alessandro Spinuso
https://portal.enes.org/data/data-metadata-service/climate4impact-portal;
https://climate4impact.eu/impactportal/general/index.jsp
The Climate4Impact portal is intended for a broad range of users, with a broad range of background knowledge. The challenge is to keep the user interface as simple as possible. However, simple for people with a lot of background knowledge on climate data is generally by far not simple enough for (first time) users (Bennett & Groot, 2015). In the case of a portal the most common way to overcome this problem is to give more guidance. This is also often requested by users (Hall, 2019). It is important to provide enough introduction in the website for a user to find out what fits his/her interest, otherwise they will get confused and will leave the portal. According to CLIPC (2016), you can never give enough user guidance.
Hamaker et al. (2017) indicate that to improve use of a portal it should contain a combination of both a good structure and tools and good guidance.
Open and free climate data can help organisations with limited budgets to develop new services, but they may also discourage the commercialisation opportunities by businesses potentially offering similar data products. Limiting access to data via a paywall is a large barrier to further uptake, though paradoxically there is an increasing awareness that costs around data collection may need to be recovered (Hamaker et al., 2017).

Data search:

- When using the search interface, this often results in a very large number of potentially interesting files (Klump, 2020). It is possible to limit the number, but then a lot more filters have to be used. Many of the potentially new users (e.g. climate impact researchers) do not know what all these filters stand for. The current filters implicitly assume a high level of background knowledge, as in many of these types of portals (Hamaker et al., 2017). Some of the filter names can be made more "logical" (e.g. "frequency" could be replaced by "time resolution"; there is no clear filter for spatial resolution/grid size, several users will not recognize that they can use "nominal resolution") or more guidance and explanation can be given (Bennett & Groot, 2015). Easier access to guidance (dynamic guidance at the location where help is needed) would be the easiest for users (Pagé et al., 2020; Fiore et al,, 2020).
- Some users do not have the resources to use a large ensemble of climate model runs, they have to make a small selection. Information from the ESMValTool on biases and changes of specific climate variables would be very useful for making such a selection. It is planned to integrate ESMValTool data (through the VA access to compute services) to help with the selection of climate model runs (Pagé et al., 2020), however, it should be tested how this information should be supplied for specific user types to make it usable.
- The "free text search" now searches in the text of all fields. Sometimes it would be easier to have the possibility to search in the filters only.
- Many users indicate that information on uncertainties is important for them. Currently there don't seem to be parameters related to uncertainty or error, which makes it impossible to search for this information in e.g. satellite data files.

Data sets:

- See paragraph 2.4.1 (also higher spatial resolution climate data sets, also more bias-corrected datasets and potentially datasets from other domains, more explanation needed about the names of climate data files).

Guidance:

- A lot of guidance is available, but it is not always easy to find in the current set-up of the portal (Klump, 2020). More dynamic guidance (e.g. "mouse over" or "information icons" where people can click on to get more info) would probably be of great help for users with relatively little background knowledge on climate data. Also, more guidance on what the various options in processing mean would help users to make the right choices (Carter & Fronzek, 2014). Some restructuring (and updating) of the guidance material may also help to find the available information. More guidance and training is needed to reach a broader group of users. An active user help desk can also broaden the use of the portal. Especially for new users that do not know where else to get help. Otherwise they may search for other tools to access and process climate data (Bennet & Groot, 2015)

- The guidance at the portal should take into account the wide diversity of users, their objectives, interests and skills (Swart et al., 2017), in order to provide usable information.
- Hamaker et al. (2017) state that freely available data can become a problem, when it is not combined with appropriate levels of support. Novice users may better first be introduced with some (on-line) tutorial or course.
- The current guidance is limited mainly to GCMs and on studies related to future climate change. However, for many users (e.g. for impact researchers) information on RCMs is also important and analysis of only the past climate may also be interesting for some users. More guidance on these types of studies would be useful.
- Some use case examples are available, but some more detailed use cases, e.g. with instruction videos or screenshots of all the steps), could help new users (and of course short trainings).
- It is unavoidable that many abbreviations and specific terminology are used. However, more explanation on e.g. the buildup of climate data file names, the climate variable names, the options from the available filters, the various experiments in CMIP, etc. would be useful for the relatively new users (Pagé et al., 2020; Carter & Fronzek, 2014).
- Many people state that uncertainty information is important, but they use this information very little. Guidance on how to calculate and/or use uncertainty information may help them to use it more (Bessembinder, 2017).

Information on processing:

- At the moment the C4I portal regularly gives error messages, sometimes takes extremely long times for processing (with regularly error messages at the end). The revised version of the C4I-portal hopefully will have less of these problems. However, it may be useful to display information on the C4I-portal about the time required for e.g. processing and on indications about the problem in the case of error messages (Pagé et al., 2020).

Processing options:

- For VIA research often tailoring of data is needed (Bennett & Groot, 2015). The requirements may differ greatly among the various sectors. A flexible tool that offers many different options to calculate tailored indices (e.g. Growing Degree Days above a certain threshold or Winkler index) would be useful for VIA and Climate services providers (Buontempo et al., 2020). Buizza (2016) states that there is a need for products to be tailored to the varied needs of different user groups for such products to be useful in their decision making. However, it is probably impossible to tailor for all potential users, but more options for processing (calculation of indices, statistics, etc.) would be interesting to attract a broader group of users (Bennett & Groot, 2015).
- Besides, VIA researchers may use different formats. Options to transform the format of the climate data into the required format would help these researchers (Bennett & Groot, 2015; Bessembinder, 2017)

- In order to guide users, there is a need to reflect on what limitations should be built into the toolbox that would stop users from creating combinations and analyses that are scientifically unjustified and potentially misleading (CLIPC, 2016)
- Bennett & Groot (2015) indicate that a tool for calendar harmonization would be useful for users. In climate models sometimes different lengths of years are used than in real life.

Quality of the data:

- As indicated before, many users find it important to have some information on the quality of the data. However, it is not always possible to determine what 'quality' means for different users and purposes (Hamaker et al., 2017). Information on provenance, uncertainties, biases in climate model data, whether climate model data are bias-adjusted, etc. will be useful for many, if this information is available in an easy accessible way (Bennett & Groot, 2015; Swart et al., 2017).

2.4.2 Services related to climate models and tools

2.4.2.1. Unified NEMO sea ice model

Contact person: Claire Levy
https://portal.enes.org/models/copy_of_nemo, https://www.nemo-ocean.eu/; users documentation: https://forge.ipsl.jussieu.fr/nemo/wiki/Users
NEMO development strategy is based on the interests of the NEMO Consortium members, so as on the feedbacks from the NEMO community. On a day to day basis, the users can interact, ask questions and make suggestions through the NEMO forums (pers. Comm Claire Levy). In September 2019 a workshop on the development strategy for sea ice modelling was held (Blockley, E. & M. Vancoppenolle, 2019). The virtual EGU session "OS4.8 Numerical modelling of the ocean: new scientific advances in ocean models to foster exchanges within NEMO community and contribute to future developments" has also been an opportunity to get feedbacks and requests from the community, and this EGU session is meant to continue to take place each year. At this stage, from these interactions, no new users requirements have been expressed: the community seems happy enough with the NEMO distribution, support and development.

2.4.2.2. Standards

- **Scientific provenance of model evaluation**

The ESMValTool implements the W3C PROV standard (https://www.w3.org/TR/prov-xml/) to transparently record the applied processing, information on the original data and other information to ensure a complete provenance record.

- **Coding standards and improving code efficiency**

The ESMValTool adheres to the respective coding standards defined for the languages it uses (e.g. PEP8 for python) as well as for its documentation and configuration files. It applies automated tests on coding styles to enforce compliance when new code enters the main branch. No other user requirements are known at the moment.

2.4.2.3. ESM services (HadGEM/UKESM, EC-Earth, NorESM, NEMO)

Contact person: Individual for each model
https://portal.enes.org/models
Model development groups provide updated versions of their respective software, documentation, contact information and user feedback channels. The central resource for basic information about all models (and tools) is the ENES Portal (see link above). Contact information and basic model/tool information has been updated on the Portal, allowing the user requirements to reach the respective groups. Particularly for ESMs, updated information for CMIP6 model versions and links to in-depth documentation on ES-DOC is provided. User requirements are typically received via the information on the Portal, or directly through the communication channels (e.g. issue tracking) linked.

2.4.2.4. Infrastructure tools

- **OASIS3-MCT coupler**

Contact person: Sophie Valcke
https://portal.enes.org/models/software-tools/oasis; https://portal.enes.org/oasis
(allows synchronized exchanges of coupling information between numerical codes representing different components of the climate system)
The last user survey was held in November 2017 (https://portal.enes.org/oasis/users/oasis-governance/surveys-on-oasis-since-the-creation-of-the-governance). A development plan based on this survey was written in 2017 and revised it in 2019 (https://portal.enes.org/oasis/users/oasis-governance/development-plans-1). The user requirements are included in the IS-ENES3 and ESiWACE projects. No new inventory of user requirements has taken place and no new insights are available at the moment.

- **XIOS**

Contact person: Yann Meurdesoif
https://portal.enes.org/models/software-tools/xios; http://forge.ipsl.jussieu.fr/ioserver/wiki
(software allowing asynchronous parallel I/O using a dedicated pool of servers for each component of a climate model. It also provides an “in situ” data workflow functionalities to make in-flight post-processing of model data within the simulation (e.g. direct production of CMIP6 compliant data))

Wang & Meurdesoif (2020) report on the development of unit tests for checking XIOS functionalities.

- **Cylc/Rose**

Contact person: David Matthews
https://portal.enes.org/models/software-tools/cylc; https://cylc.github.io/
(general purpose workflow engine that orchestrates cycling workflows)
Priorities for development are described in M8.2 (Matthews, 2019). A distinction is made between the highest priorities and immediate priorities beyond Cylc 8 and Rose 2. Priorities will be constantly reviewed based on progress and user feedback.

- **ESMValTool (standardized model evaluation)**

Contact person: Veronika Eyring, Björn Brötz.
https://www.esmvaltool.org/
(Diagnostic and performance metrics tool for routine evaluation of Earth system models in CMIP)
A survey will be executed among (potential) users in the months of June to October 2020 (WP3-NA2, task 4.2) by Assimila about the services and technical requirements. More detailed information about user requirements will become available with the report of this survey. The roadmap (https://www.esmvaltool.org/roadmap.html) outlines the ESMValTool developments that are planned already roughly until the end of 2022.

Until now the results of ESMValTool have been used mainly for model evaluation, to check whether they perform well against observations/re-analysis, to check how they differ from earlier model versions, to check what is the projected change in the future, etc. However, results of the model evaluation (e.g. of all CMIP6 or CORDEX) may also be useful for impact research or climate service providers (see under 2.4.1 “derived data”). Several of the requirements that are needed for these applications are included already in the current tool (Eyring et al., 2019; Right et al., 2020). E.g. it is possible to calculate extreme percentiles for precipitation and temperature, several (combined) climate extreme indices are available. For the selection of model runs and bias-adjustments, biases for specific countries or regions are needed rather than the average bias over larger regions. The ESMValTool allows for such an analysis as documented here for the “runoff, precipitation, evapotranspiration diagnostic”: https://docs.esmvaltool.org/en/v2.0.0b3/recipes/recipe_runoff_et.html. However, biases and changes can also be determined for lat-lon fields if needed. Most climate variables that are interesting for model selection purposes and bias-correction can be determined already, although a further inventory may be needed. Additional variables can be easily added if observations are available. Besides, the tool is compatible with any arbitrary model output as long as it is in CF-compliant netCDF format (Eyring et al., 2019). The main question is how this information can be made available in an easy and usable way for these purposes.

3. Difficulties overcome

Due to COVID19 there have been less face-to-face meetings. These meetings are, in general, very useful to collect information on user requirements or wishes. The questions asked and discussions during these meetings often reveal user requirements, directly or indirectly by showing where users experience problems.

The short trainings and demonstrations were planned to show, among others, how users could profit from the Climate4Impact portal. The current version is rather slow, and the portal is now under reconstruction, which is somewhat delayed. This limits the number of demonstrations where information on user requirements can be collected. For this reason, the first "Impact school" is delayed also from the first half of 2020 to autumn 2020 (or later if travel restrictions due to COVID-19 persist or are imposed again).

4. Next steps

This interim report only presents an intermediary overview. The collection of material on user requirements will be continued in many ways (workshops, inventories, interviews, literature, etc.). Annex 1 lists which activities in the IS-ENES3 project could give more insights in user requirements. Some have taken place already, others not yet. Besides these activities, sources from outside this project will be consulted. This document is also meant as an overview for other WPs within the IS-ENES3 project. At the end of this project a final report on user requirements will be produced.

Although it will not be possible to include all user wishes or requirements within the activities of the current IS-ENES3 project, it may be good to keep the user wishes/requirements in mind during the current activities to keep options open as much as possible to include the wishes/requirements in a later stage. Some of the wishes/requirements may also be realized by some additional user guidance or training. A clear and organised user requirements capture is also key to the sustainability activities of IS-ENES3.

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Relevant links

CF workshop https://drive.google.com/drive/folders/1LzgP7wwSzz55giCVZyk-4xiu28gp68Fg
CIM standard https://www.dmtf.org/standards/cim
Climate4Impact (C4I) https://climate4impact.eu/
CLIP-C http://www.clipc.eu/
CMIP https://www.wcrp-climate.org/wgcm-cmip
Copernicus https://climate.copernicus.eu/
CORDEX https://cordex.org/
CORE-CLIMAX https://cordis.europa.eu/project/rcn/106564/reporting/en
DataCite https://datacite.org/index.html
ESGF (Earth System Grid Federation) https://esgf.llnl.gov/index.html
ECA&D https://www.ecad.eu/
ENES https://portal.enes.org/
EOSC portal https://www.eosc-portal.eu/
EGI https://www.egi.eu/tag/eosc/
ES-DOC https://es-doc.org;
ES-DOC Explorer https://explore.es-doc.org;
ES-DOC Errata https://errata.es-doc.org/
EUDAT https://www.eudat.eu/
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IMPACT2C https://www.atlas.impact2c.eu/en/
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ISIMIP Inter-Sectoral Impact Model Intercomparison Project): https://protocol.isimip.org/; https://esg.pik-potsdam.de/projects/isimip/ https://www.isimip.org/protocol/preparing-simulation-files/
Obs4MIPs https://esgf-node.llnl.gov/projects/obs4mips/
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WDCC https://www.dkrz.de/up/systems/wdcc
WGCM Infrastructure Panel https://www.wcrp-climate.org/wgcm-cmip/wip
WGCP (Working Group on Coupled Modelling) https://www.wcrp-climate.org/wgcm-overview
WCRP (World Climate Research Programme) https://www.wcrp-climate.org/
WMO https://public.wmo.int/en

Annex 1: Overview of relevant deliverables, milestones and activities in IS-ENES3 for user requirements per WP

WP2- NA1: Governance, Sustainability and Innovation

- MS7 Innovation Plan (mo 12; UKRI)
- MS8 Sustainability Scoping Report (mo 24; DKRZ)

WP3- NA2: Community engagement

- D3.1 Initial requirements on model evaluation (mo 18; CNRS-IPSL)
- D3.3 Standards synthesis (mo 36; UKRI) synthesis of the workshops on standards including scientific provenance for model evaluation
- D3.4 CMIP documentation requirements (ES-DOC services) (mo 36; UREAD-NCAS)
- MS11 First school on climate and impacts (mo ?; WENR)
- MS12 Synthesis of first 5 short events to broaden community (mo 24; KNMI)
- MS13 Summary of workshops on standards (mo 24; UKRI)
- MS14 Workshop on climate indices (mo 26; FPUB)
- Short trainings, demonstrations and webinars (all 4 years; all partners)
- Workshop climate indices requirements in Eastern Europe (mo 24; SMHI)
- Schools on the interface between climate and impact models (mo 24, mo 30; WEnR).
- School on Climate Data Science.(mo 34; NCSR-D, CMCC, DKRZ)
- Workshop Vocabularies and standards for CMIP (mo 9; UKRI)
- Workshop data Standards for Climate Indices (metadata standards, tools, software) (mo 15; SMHI)
- Workshop Climate and Forecast Convention (CF) (mo 19; UC, UREAD-NCAS)
- Standard on scientific provenance of model evaluation (CNRS-IPSL, KNMI, DLR)
- Community survey to review the needs and expectations of a variety of end users (mo ?; CNRS-IPSL)

WP4- NA3: Networking on Models, Tools and efficient use of HPC

- D4.1 : Coupling workshop report [mo 17; CERFACS]
- D4.2: Development Strategy for Sea Ice modelling toolset (mo 26; Met Office)
- D4.3 : Computational Performance of MIP metrics and community advice [mo 35; BSC]
- D4.4 : NEMO QA update (technical and scientific) [mo 40; CNRS-IPSL]
- MS16 New technical opportunities workshop in ML and AI (mo 24; UNIMAN)
- Task 2: collaborative development of a unified NEMO sea ice (NEMSI) model. (Met Office)
- Task 5: International Workshop on Coupling Technologies for Earth System Models (CERFACS)

WP5- NA4: Networking on data and model evaluation

- D5.1 : Compute service requirements and state of the art approaches (mo 12; CERFACS)
- D5.2 : Technical standards for diagnostic tools [mo 24; BSC)
- D5.4 : IS-ENES3 involvement in ESGF [priorities; mo 36; DKRZ)
- D5.5 : Style guide on coding standards [technical, for ESMValTool; mo 36; NLeSC)
- MS20 Requirements for technical standards for diagnostic tools 6 - BSC (mo 20; BSC)
- workshop to discuss user requirements, gaps, and challenges for the IS-ENES compute service (D5.1; mo 12; CMCC and CERFACS)

WP6- VA1: Services on European ESMs and Software Tools

- D6.2 : First external review of model and tools services (mo 24; SMHI)
- D6.3 : Second periodical report on service statistics for models and tools (KPIs; mo 36; CERFACS)
- D6.4 : Report on new OASIS coupled models/interfaces [new needs; mo 36; CERFACS)
- D6.5 : Second external review of model and tools services (mo 40; CERFACS)

WP7-VA2: Data standards, distribution and processing services

- D7.1 First KPI and TNA report for ENES CDI services (mo 18; DKRZ)
- D7.2 : First external review report for ENES CDI services (mo 24; KNMI)
- D7.3 : Second KPI and TNA report for ENES CDI services (mo 36; DKRZ)
- D7.4 : Second external review report for ENES CDI services (mo 40; KNMI)
- D7.5 : Report on operational support for CMIP documentation (mo 43; CNRS-IPSL)
- D7.6: Third KPI an TNA report for ENES CDI services (mo 48; DKRZ)
- MS26 ENES CDI help desk (mo 8; DKRZ)
- Help desk. DKRZ, CNRS-IPSL and UKRI acting as first level support with respect to ESGF related data provisioning and KNMI acting as first level support for the impact community oriented services. SMHI provides support functions with respect to CORDEX and the regional climate modelling community. DKRZ and KNMI will be responsible to collect and provide up-to date documentation, FAQs and contact addresses,
- Annual workshops in the different CORDEX domains worldwide

WP8- JRA1: Models & Tools developments

- MS31 Cylc/Rose development priorities agreed (mo 12; Met Office)
- MS32 Final list of developments for OASIS3-MCT_5.0 (mo 24; CERFACS)

WP9- JRA2: Earth System Model Evaluation developments

- coding workshops on the ESMValTool (DLR, BSC)
- Task 8:Distributed ESMValTool computing and calculations on user demand (NLeSC, BSC, DLR, CNRS-IPSL)

WP10- JRA3: ENES Climate Data Infrastructure software stack developments

- D10.1 : Architectural document of the ENES CDI software stack (mo 18; CMCC)
- MS37 Technical requirements on the software stack (mo 14; CMCC)
- MS38 CMIP data request schema 2.0 (mo 18; UKRI)

- MS39 Climate indicators/indices and file metadata specifications and tools (mo 24; SMHI)
- MS40 Update of the climate indicators/indices and file metadata specifications and tools (mo 48; SMHI)
- Task 3: Improve the user interface and functionalities of the climate4impact platform for the impact communities

Annex 2: Glossary

Acronym	Explanation
ADAGUC	Atmospheric Data Access for the Geospatial User Community
API	Application Programming Interface
C4I	Climate4Impact
CCI	Climate Change Initiative
CDI	Climate Data Infrastructure
CDO	Climate Data Operators
CF	Climate Forecast
CLIPC	Climate Information Platform for Copernicus
CLIVAR	Variability and predictability of the ocean-atmosphere system
CORE-CLIMAX	COordinating Earth Observation Data Validation for RE-Analysis for CLIMAte ServiceS
CMIP	Coupled Model Intercomparison Project
CMOR	Climate Model Output Rewriter
C3S	Copernicus Climate Change Service
CORDEX	Coordinated Regional climate Downscaling Experiment
DDC	Data Distribution Centre
DOI	Digital Object Identifier
ECAS	ENES Climate Analytics Service
ECA&D	European Climate Assessment & Dataset
ENES	European Network for Earth System Modelling
EOSC	European Open Science Cloud
ES-DOC	Earth System Documentation
ESGF	Earth System Grid Federation
EUPORIAS	European Provision of Regional Impacts Assessments on Seasonal and Decadal Timescales.
GUI	Graphic User Interface
ICCLIM	Indice Calculation CLIMate
IMPACT 2C	Quantifying projected impacts under 2°C warming
Input4MIPs	Input Datasets for Model Intercomparison Projects
IPCC	Intergovernmental Panel on Climate Change
IPCC AR6	IPCC Assessment Report 6
IPCC TG-Data	Task Group on Data Support for Climate Change Assessments
IS-ENES	InfraStructure for the ENES modelling
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
MIPs	Model Intercomparison Projects
NA	Networking Activity
NCO	NetCDF Operators
NetCDF	Network Common Data Form
Obs4MIPs	Observations for Model Intercomparisons Project
OGC	Open Geospatial Consortium

PCMDI	Program for Climate Model Diagnosis & Intercomparison
PID	Persistent Identifier
QA4ECV	Quality Assurance for Essential Climate Variables
TNA	Trans-National Access
UI	User Interface
WCRP	World Climate Research Programme
WCS	Web Coverage Service
WDCC	World Data Center for Climate
WGCM	Working Group on Coupled Modeling
WIP	WGCM Infrastructure Panel
WMO	World Meteorological Organization