The **CLIMSAVE** Project

Climate Change Integrated Assessment Methodology for Cross-Sectoral Adaptation and Vulnerability in Europe

Report describing the Integrated Assessment Platform (IAP) specification, meta-model specifications and the multi-scale approach

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Introduction

Deliverable 2.1 reports on three Tasks associated with the development of the Integrated Assessment Platform (IAP):

1. Development of the specification of the user-friendly interactive web-based platform (Task 2.1).
2. Development of the meta-model specifications (Task 2.2).
3. Development of the multi-scale approach to meta-model application (Task 2.3).

The development of the CLIMSAVE Integrated Assessment Platform will be iterative, as it undergoes modifications through the duration of the project in response to progressive stakeholder feedback from the activities of Work Packages 1 and 3 and from direct stakeholder engagement via the CLIMSAVE website. As such the activities described in this report represent 'works in progress', rather than being 'set-in-stone'.

Task 2.1: Development of the specification of a user-friendly interactive web-based platform

The fundamental concept underpinning the specification of the IAP is to deliver rapid interactivity for the user, for which the CLIMSAVE IAP will utilise the world wide web. This technology provides a flexible and familiar interface to stakeholders, which should vastly broaden accessibility and stakeholder participation and increase impact in research communities. This contrasts with other IA platforms, which rely on either PC software installation (either freeware or commercial), advanced academic computing networks or only utilise the web for visualisation of results.

In developing an integrated web-based system, one of the major challenges involved in the construction of the CLIMSAVE IAP is to build a common software platform intended to link 12 disparate meta-models from various sectors (modelling indicators of the urban, agricultural, forest, water resources, biodiversity, fluvial and coastal flooding 'sectors') which have been developed by eight different European research organizations, and where every research organization has a particular approach to modelling and software development.

There have been two principle work areas associated with the development of the specification of the web-based IAP. The first involves technological issues around software selection, data transfer and data storage including, based on analysis of the common available resources, the decision to use a common Windows-based software platform to develop the IAP (Milestone 2.1) rather than a web distributed multi-platform. The second involves the design of the stakeholder/user graphical interface, which is based on a cycle of continuous iterative improvement through dialogue within the CLIMSAVE consortium and with stakeholders throughout Work Package 1 and 3 activities.

Technological specification of the IAP

Rapid user interactivity via the web requires efficient communication between the user sitting at their computer and the remote server containing the meta-models and the underlying physical (soils, land-use, etc) and scenario (climate and socio-economic) datasets.

The technical construction of the CLIMSAVE IA platform is based on a web Client/Server architecture that will use both server-based and client-based computing solutions on the web. The meta-models will be developed for use with server-based web technologies, as this negates the need for input data transfers to the user (and hence the requirement for the user to sign data licenses) and maximises access speed. The web-based interface for stakeholders will be developed using a client-based computing solution as this allows (1) fast reply to the user actions; (2) the output data from meta-models (server-based) to be sent synchronously and asynchronously to the client based Interface, as output data from faster meta-models can be displayed by the user whilst other meta-models finish their run to give the impression of a real-time response; and (3) the opportunity to use map services (e.g. Google Earth, Bing Maps) to display spatial data.

The Client/Server architecture relies on two main computer programs: one on the Client computer (the Client Interface Module) and one on the Server (the Running Module) as shown in Figure 1.

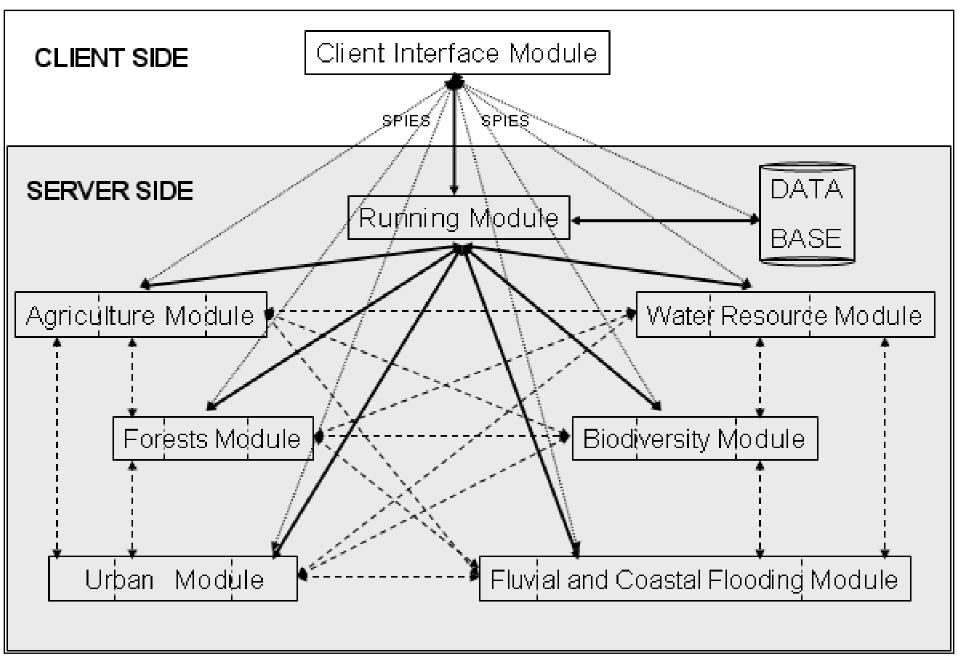

Figure 1: Schematic of the structure of the CLIMSAVE IAP.

The user will directly interact with the Client Interface Module which will be on the user's desktop at an assumed screen resolution of 1024 x 768 pixels. This will be developed using Microsoft Silverlight technology. Microsoft Silverlight is a Rich Internet Application (RIA) framework that integrates computer graphics, multimedia, web services and interactivity into a single runtime environment. It is compatible with web browsers used on both Microsoft Windows and Mac OS X operating systems, whilst a free software implementation named Moonlight (developed by Novell in cooperation with Microsoft) is available to bring most Silverlight functionality to Linux, FreeBSD and other open source platforms.

As the user interacts with the CLIMSAVE IAP Interface on their desktop (see next Section), the underlying Client Interface Module will collect the information for the user's simulation selections (such as the choice of climate scenario, input parameter values, etc) and send these requirements to the Server. The availability of meta-model output data for the requested simulation from the server will be checked from the Client side by the Client Interface Module sending false requests to the servers (known as spies). When ready, the Client Interface Module will then collect the output data delivered by the Server for display to the user in the user-friendly graphical interface.

On the Server computer will reside the following components:

- the main CLIMSAVE database which will organize the physical, climate, socio-economic and other temporary datasets required as inputs for the meta-models. It will be defined, organized and managed as a Microsoft SQL Server 2005/2008 database which is a relational model database. The database structure is under development at the current time;
- (12) meta-models structured as Microsoft Dynamic-Link Libraries (DLL), for simulating the urban, agricultural, forest, water resources, biodiversity, fluvial and coastal flooding sectors. Some of these DLLs may have their own databases to extract their internal data and some of them may also directly interact with other meta-model DLLs;
- a main Running Module based on ASP (Active Server Pages) / WebService technology which will collect queries from the Client Interface Module, analyze them, interrogate the CLIMSAVE main database for the required input data for the requested simulation, prepare the data for the meta-models, run the integrated flow of meta-models in an optimized way and send back the requested information to the Client Interface Module.

Design of the IAP

Providing pre-defined results or interpretations to stakeholders based on the outputs of particular simulations of an IA is not sufficient to test the sensitivity of the system, to engender organizational or behavioural change or to enable knowledge creation as a learning process (Holman *et al.*, 2009). It represents a one-way flow of information, rather than a two-way iterative process of dialogue and exploration of "what if's". Interactive IA systems, such as the CLIMSAVE IAP, are needed that allow stakeholders to develop their understanding and test ideas, based upon their own hypotheses.

The CLIMSAVE project is developing a highly intuitive interface that should enable an interested individual to use the CLIMSAVE IAP with minimal recourse to help files and, importantly, without need for training. The members of the CLIMSAVE consortium have considerable experience in the development of user interfaces, including the Regional Impact Simulator (Holman *et al.*, 2008; Holman and Harman, 2008), CLIMPACTS (Kenny *et al.*, 2000), SimCLIM (Warrick *et al*. 2005) and MULINO (Guipponi et al., 2004; Guipponi, 2007). Based upon partner experience, examination of other participatory model interfaces (including GB-QUEST – Carmichael *et al*., 2004; Climate Wizard- www.climatewizard.org/) and potential user requirements, a list of design concepts were identified for the user interface:

- Design
  - The layout of the user interface should be informed by the CLIMSAVE framework, allowing the user to understand potential sectoral and cross-sectoral impacts, evaluate the effects of adaptation on these potential impacts and to assess the costs of adaptation;
  - The user should be able to vary model input parameters within numerical ranges, rather than through qualitative descriptors of magnitude, to increase the transparency of the model/scenario assumptions (Schneider, 1997);
  - Guidance must be given to constrain 'realistic' ranges of values within scenarios and to account for uncertainty (Turnpenny *et al*., 2004);
  - The user should be able to concurrently view and compare output from more than one meta-model;
  - Tooltips should be used to provide on-screen user guidance;
- Speed
  - The user should not need to go through an extensive or prolonged model set-up;
  - The run times should be as short as possible to prevent users getting bored and disengaging, based on typical commonly available moderately specified systems.

Through discussion with members of WP2, other WP leaders and the CLIMSAVE international experts, a preliminary list of design functionality was agreed, based on likely stakeholder expectation. These included allowing the user to:

- Select more than one timeslice;
- Select the global scale emissions scenario (SRES);
- Select climate outputs from a range of Intergovernmental Panel on Climate Change (IPCC) Global Climate Models (GCM) and/or Regional Climate Models;
- Select the climate sensitivity (the measure of how responsive the temperature of the climate system is to a change in radiative forcing, usually expressed as the temperature change associated with a doubling of the concentration of carbon dioxide in the Earth's atmosphere);
- Conduct sensitivity and uncertainty analyses;
- View model outputs as conventional impact indicators and as indicators of ecosystem services;
- View model outputs in a variety of forms, e.g. maps, tables, graphs;
- View model outputs at a range of scales of aggregation, e.g. grid scale / NUTS3 / NUTS2;
- Export model outputs for subsequent analysis;
- Zoom in, zoom out and pan across mapped model outputs, within appropriate limits.

Currently the CLIMSAVE IAP is moving from design 'mock-ups' to a prototype web interface. A prototype web interface has been developed for the first component of the CLIMSAVE framework, as shown by the *Biophysical Impacts* tab (Figure 2), whilst the second component (the A*daptation* tab) is currently at an earlier stage of development (Figure 3).

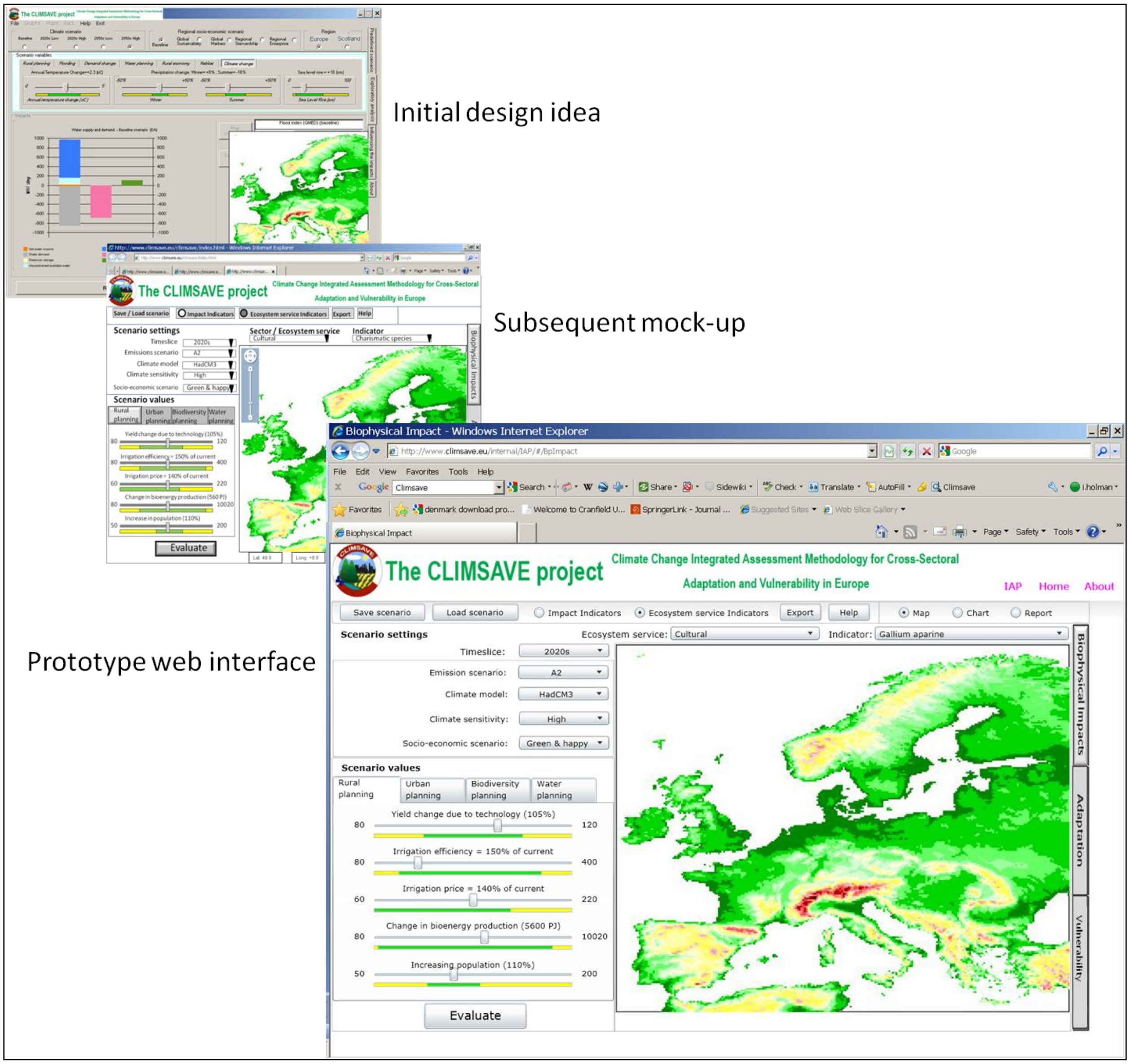

Figure 2: Initial evolution of the Biophysical Impacts tab of the CLIMSAVE IAP from initial design concept to prototype web interface.

The current prototype version for the Biophysical Impacts tab (Figure 2) embeds these design principles. For example, a traffic light-based system of colour coding of the slider bars is used to communicate the parameter uncertainty within a scenario; green denotes uncertainty that is "credible" within the context of a scenario storyline (green for 'go'); yellow denotes wider uncertainty that may be possible, but which is outside of the considered wisdom for the scenario (yellow for 'caution'). For obvious reasons, a user is not permitted to enter a red, or 'no go' zone. The user is able to explore the current sensitivity of the baseline sectors through modifying the baseline climate, so that when the baseline climate is selected (as opposed to a future climate change scenario), temperature, precipitation and sea level rise sliders appear which the user can modify. The user can also explore future climate uncertainty through modifying the choice of global emissions scenario, GCM, and climate sensitivity.

Once the user has explored the potential biophysical impacts, they can explore the potential for adaptation to reduce those impacts (Figure 3). However, the degree of adaptation within the IAP is constrained by two factors. Firstly, the amount of any one adaptation response that can be implemented is constrained by the socio-economic storyline, and indicated by the green ‘credible’ range on the adaptation response slider – for example, allowing large crop yield increases due to biotechnology might not be compatible with an environmentally-focussed storyline. Secondly, the cumulative amount of adaptation is limited by the available capital (natural, manufactured, human, social and financial) – as the user changes the adaptation slider, the capital meter qualitatively indicates how much capital would be used, with the width of the bar against each capital type indicating the uncertainty in the adaption-capital relationship derived by Work Packages 4 and 5. The financial cost of adaptation will be evaluated from non-linear adaptation-cost relationships being developed in Work Package 4.

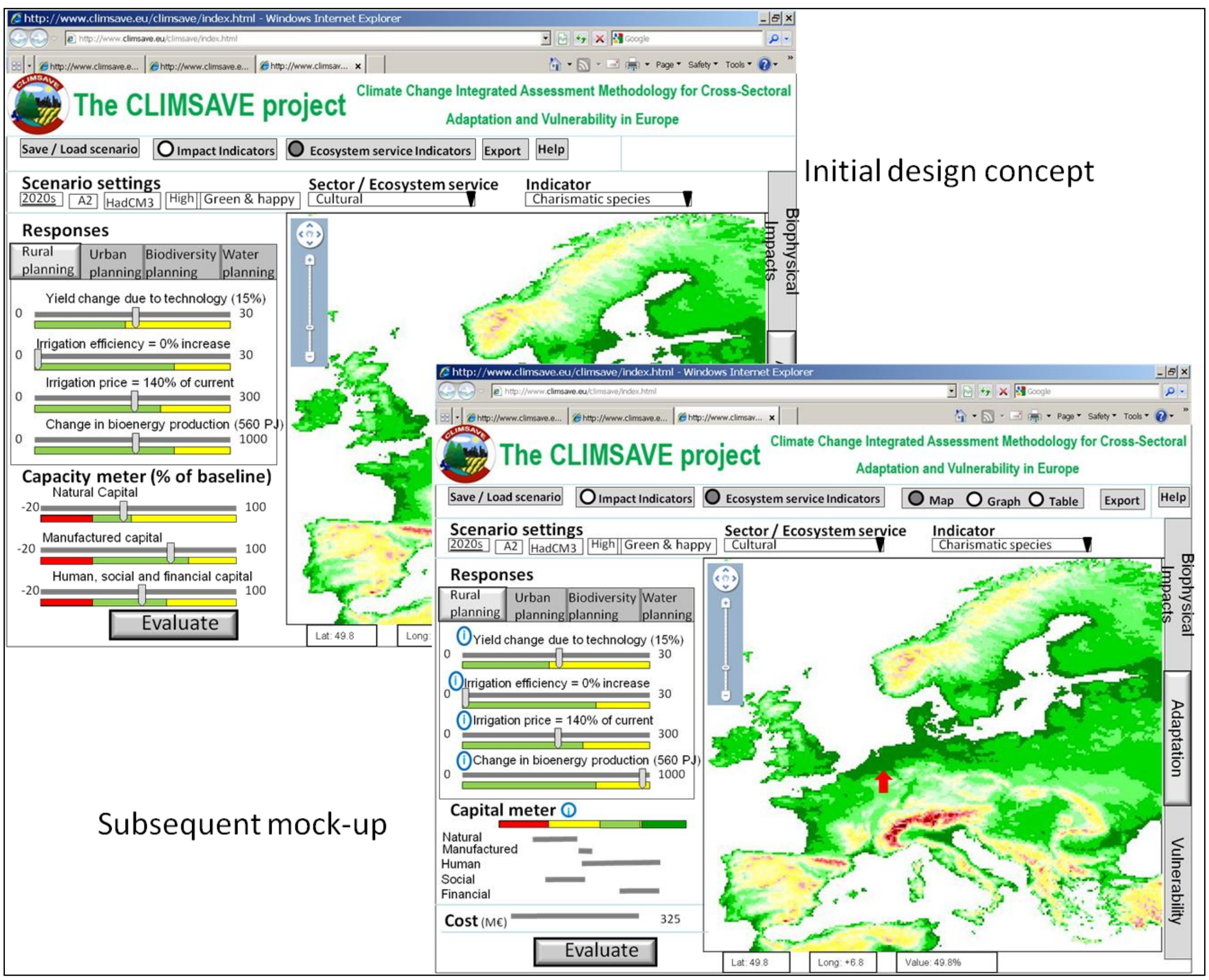

Figure 3: Initial evolution of the Adaptation tab of the CLIMSAVE IAP from initial design concept to mock-up.

Given the participatory approach to the design (van Asselt and Rijkens-Klomp 2002), which underpins the CLIMSAVE project, we anticipate that the IAP will undergo many iterations in its design following successive elements of the stakeholder engagement, including the representation of vulnerability.

Task 2.2: Development of the meta-model specifications

For efficient development of the CLIMSAVE IAP, each of the computationally-efficient models or meta-models (covering urban and rural land allocation, crop yields, forest, water resources, flooding and biodiversity) are designed to be modular, independent and capable of replacement at any time. A meta-model specification has therefore been developed to ensure successful linkage and integration of the models, irrespective of the final algorithms inside each of the models. The specifications have been defined in relation to anticipated stakeholder needs (WP1), the vulnerability framework (WP5), the scenario methodology and climate and socio-economic scenario variables (WP3) and the requirements of the adaptive capacity methodology (WP4), plus some redundancy for future development.

The development of the specification has gone through five distinct stages:

1. Defining the spatial resolution of the data to be transferred between meta-models;
2. Identifying and prioritizing meta-models inputs and outputs;
3. Identifying points of contact between the meta-models;
4. Specifying the data dictionaries for each meta-model;
5. Standardizing the data dictionaries across all of the meta-models.

For the European scale case study application of the CLIMSAVE IAP, the spatial scale of data transfer between the meta-models represents a compromise between the scale of available harmonised datasets, model runtime and spatial detail of the outputs. The higher the resolution at which the IAP operates, the greater is the number of times that the meta-models have to run and hence the greater the overall runtime of the IAP. It was agreed that the CLIMSAVE IAP would operate at a resolution of 10’ x 10’ (10 minute by 10 minute), using the same grid as the Climatic Research Unit’s baseline 1961-90 climatology (CRU CL 2.1- Mitchell et al., 2003). This represents over 23,000 land-based grid squares across the CLIMSAVE European case study. Although this represents the scale at which data is transferred, it does not necessarily represent the scale at which individual meta-models are operating – for example, the simulation of crop yield and agricultural land allocation operate at the sub-grid level (as they recognise that there are multiple soil types in each 10’ x 10’ grid square, with consequent restrictions on soil workability, timing of agricultural operations, etc), whilst the hydrology is simulated at the river basin scale.

In order to deliver the fast web-based response time demanded by this application a process of meta-modelling is being carried out on each of a set of tried and tested desktop models to abstract the leanest representation consistent with delivering both functionality and speed. Based upon the state-of-the-art sectoral impact models available to the consortium (as outlined in the Description of Work), model inputs and output were identified by the modellers and rated for stakeholder-relevance by the CLIMSAVE consortium. For the model inputs, the prioritization was based on their relevance to adaptation responses – for example, "technological change" in water use within the domestic sector was highly prioritized because of its potential importance in leading to improvements in the efficiency of water use and a decrease in water intensity, as seen by the water intensity of washing machines in German households dropping by 2% per year over a 15-year period. The model outputs were prioritized according to perceived stakeholder relevance (e.g. areas at risk of flooding and flood damages) and/or policy relevance (e.g. rural land-use allocation for intensive agriculture, extensive agriculture, abandoned land, etc).

Points of contact were also identified between the meta-models (Figure 4) – these are the linkages and influences between sectors, and represent data transfers between the models. For example, following the flow arrows from the RUG model in Figure 4, the simulated area, location and type of urban development ("artificial surfaces" and "residential/non-residential development" from the urban model – RUG) affects the population exposed to flood risk ("People affected" as estimated by the Flood Model), river basin hydrological response ("Basin flow" from WaterGAP-H), the land available for agriculture and forestry ("landuse allocation" from the land allocation model – SFarmMod) and consequently habitat availability (biodiversity models – SPECIES and LPJ-GUESS).

Given the identified points of contact between the meta-models, and the resultant flow of data, the order of operation of the models (indicating whether it may be possible for them to operate in series or parallel) has been identified, as shown by the numbering and large open arrows in Figure 4. For example, the meta-models which are arranged horizontally alongside the number 1 can all operate in parallel as they are independent on each other; whereas WaterGAP-H and WaterGAP-U are dependent on outputs from the first sequence of models (specifically RUG), and will pass their outputs to the meta-model in the third step (FloodModel).

Within any single simulation of the CLIMSAVE IAP, there will be five components of data reading and transfers:

1. Data transfers from the user to the meta-models, representing the communication of input parameter values from the user (slider bars, timeslice, scenarios, etc) to the models, via the Running Module;
2. Data transfers between the meta-models, where the simulated output from one meta-model is an input to other meta-models;
3. Data transfers between the meta-models and the user Interface, as outputs are selected by the user for display;
4. Data transfers from the IAP database to the meta-models containing, for example, the input data for a user-selected scenario;
5. Data that is read into a meta-model from the meta-model's own internal dataset.

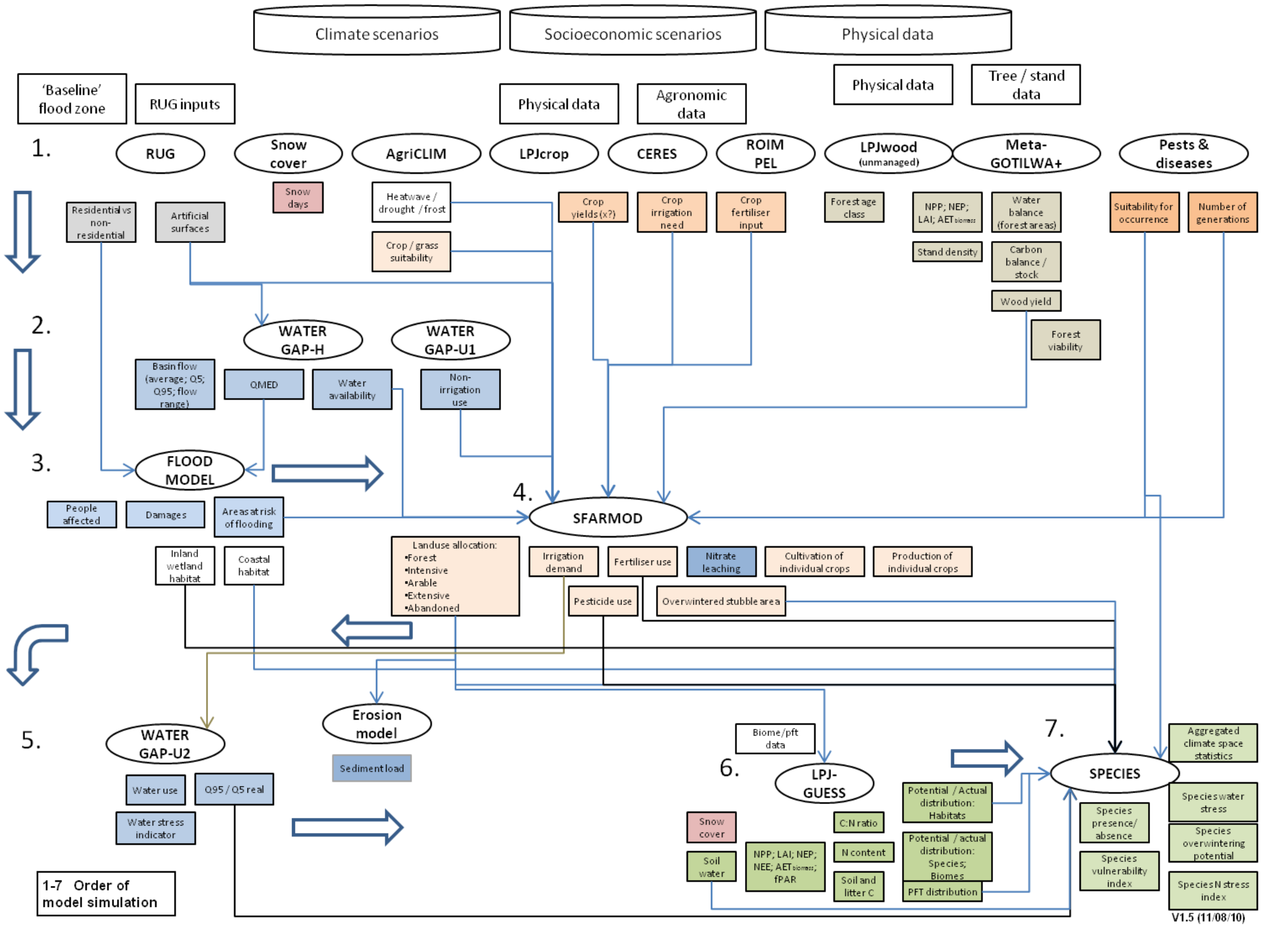

Figure 4: Draft schematic of the data interactions between the meta-models [Ovals represent the meta-models; open rectangles represent data inputs from the databases; shaded rectangles represent meta-model outputs; numbering and large open arrows indicates the order of operation of the meta-models].

With the exception of (5), all of the above represent transfers of data which need to be clearly defined in a transparent way for the consortium. Data dictionaries have therefore been developed for data associated with (1) – (4), which define for each variable or parameter:

- Whether it is an input to, or output from, the meta-model;
- If it is a meta-model Input, where it comes from – the IAP database; the user via the IAP; or another (named) meta-model;
- Variable or parameter name as used by the meta-model's code, prefixed by the name of the model e.g. RUG_PArtS_rdif is an output variable from the RUG model;
- Long variable or parameter name, i.e. the conventional name given to the model parameter for example, RUG_PArtS_rdif is the 'Relative change in artificial surfaces';
- Definition of parameter or variable – providing an unambiguous 'plain English' explanation, for example RUG_PArtS_rdif is the 'Percentage difference in artificial surfaces relative to the baseline value';
- Dimensions - Single; Integer8, 16, or 32;

- Units;
- Spatial unit - whether the data is provided for each grid cell, polygon, river basin, cluster, NUTS2, country, or a global value;
- Number of values per spatial unit, which allows for, for example, multiple soil types within a single grid cell;
- For Outputs, what is the destination of the variable within the IAP - whether it to be used by another meta-model(s) and/or displayed in the Interface.

The final step in the process is the standardization of the data dictionaries across all of the meta-models, so that each end (IAP, database or meta-model) of a data transfer (for example, meta-model to meta-model; or IAP to meta-model) uses the same data dictionary. This then allows the data transfers in terms of model variables and parameters to be defined (Figure 5).

The meta-models themselves are implemented as Dynamic-Link Libraries (DLL) developed in various software languages: Microsoft C++, Microsoft C#, Microsoft VB, and Delphi as both managed and unmanaged code. They will be embedded in the main Running module, working as one piece of software. The Running module will feed the DLLs with data, run the DLLs and collect the outputs. The exchange of data will be made available based on structures of data transferred by pointers to minimise the time required for data exchange. In this approach, the meta-model is told where to point data within the internal memory, rather than the data being physically transferred to the model, with consequent time savings given the number of grid cells (>23,000).

Task 2.3: Development of the multi-scale approach to meta-model application

Adaptation decisions are made at multiple scales from household to site/catchment up to the European Community and beyond. Within CLIMSAVE, the IAP will operate at two scales, represented by the EU26 + 3 (which includes Norway, Switzerland and Liechtenstein, but excludes Cyprus as it is outside the area of the baseline climatology of Mitchell et al., 2003) and by a regional case study (Scotland). Four options for the multi-scale approach to applying meta-models which are consistent with the philosophy of the CLIMSAVE IAP have been identified within Task 2.3:

1. Enabling variable upscaling of the viewing scales;
2. Enabling statistical downscaling of output data.
3. Enabling variable input data spatial resolutions, or;
4. Enabling variable clustering of the existing input data.

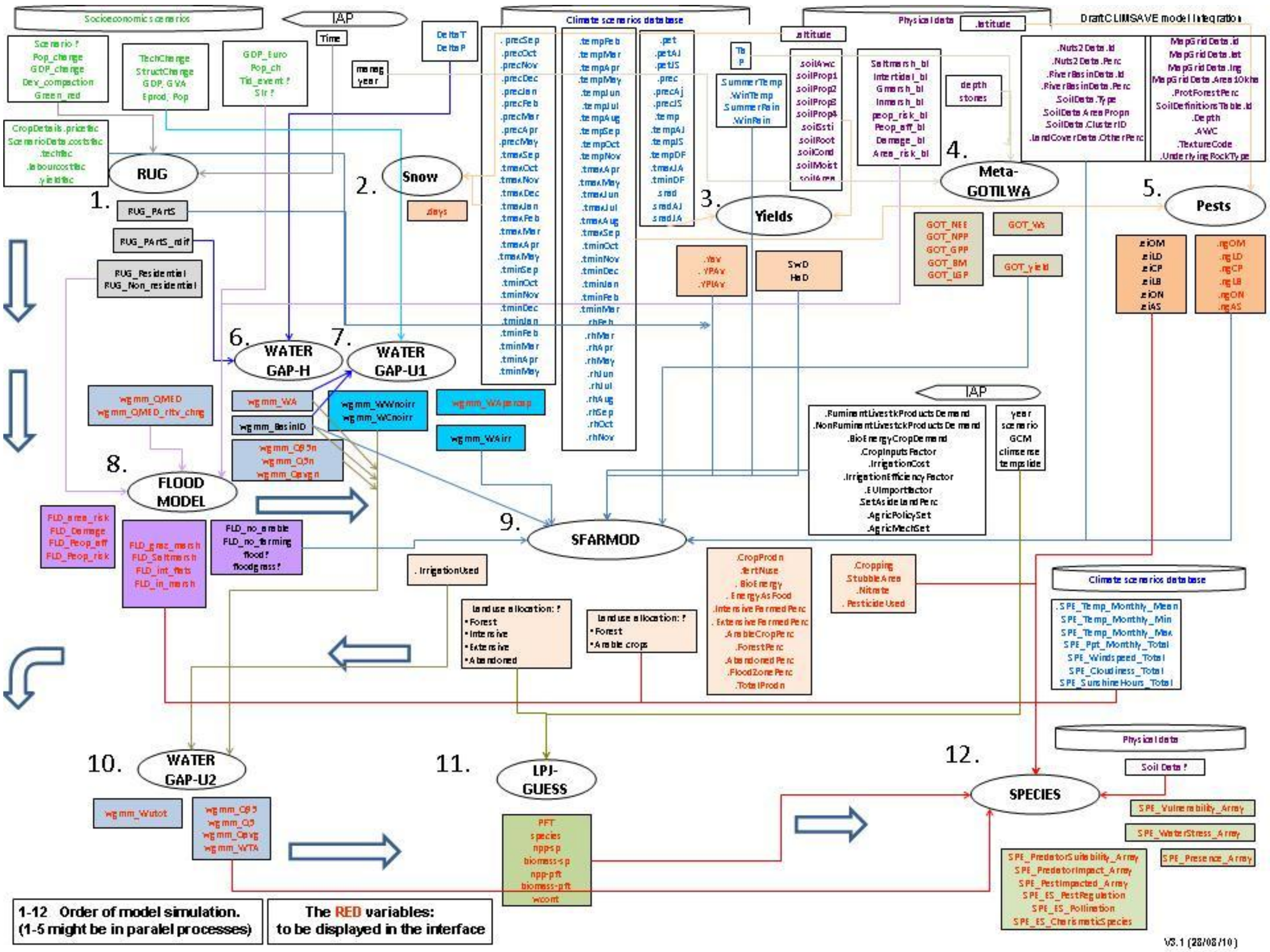

Figure 5: Schematic of the data transfers according to model variable and parameter name [numbers and open arrows indicate the order in which the server will prioritise the processing of the meta-models within the 4 core processors].

Approach 1: Enabling variable upscaling of viewing scales

This represents the simplest approach for providing multiple scales to users, whereby outputs from the IAP are displayed at different scales using different levels of spatial aggregation of the 10' output (Figure 6). At the European scale, outputs could be displayed for visualisation at NUTS 0 (country) or NUTS 2 (sub-national regions), equating to around 30 to 350 spatial units. With the intended zoom functionality in the European interface, which would allow the user to zoom to regions of Europe, outputs at NUTS 3 resolution would increase the number of spatial units to around 1500 across Europe. Finally, at both the levels of the regions of Europe and the regional case study, the underlying 10' x 10' model output could be displayed - this latter resolution would represent more than 450 spatial units within Scotland.

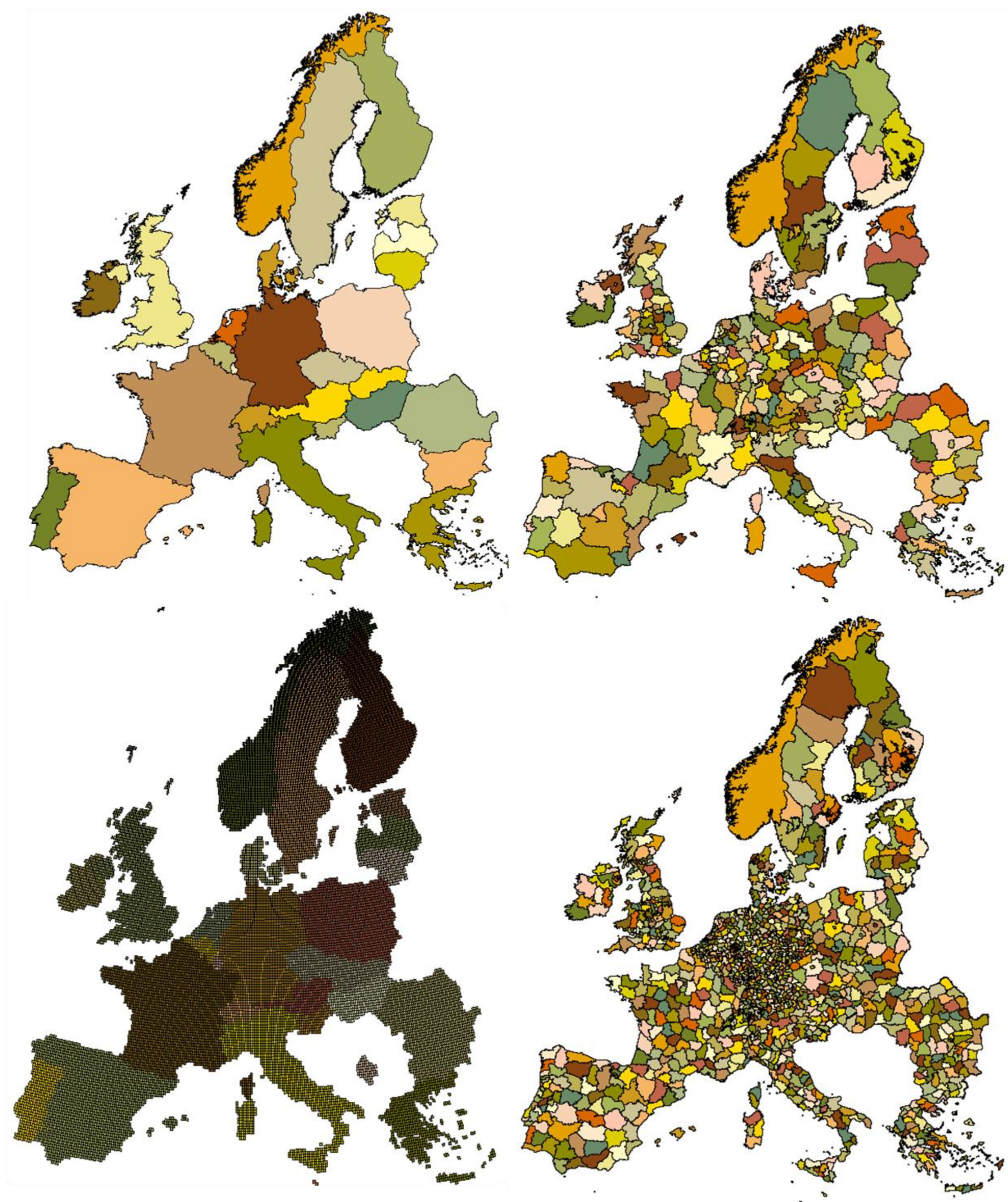

Figure 6: The effects of changing the viewing aggregation scale (from clockwise from top left) from country/NUTS0 to NUTS2 to NUTS3 to grid square.

Approach 2: Statistical downscaling of output data

To counteract the perceived lack of spatial detail in the 10' x 10' grid, downscaling methods can be used to add spatial detail. In its simplest form, statistical interpolation between the grids could be used to provide a smoother rather than pixelated view of the 10' grids (Figure 7). Alternatively, additional spatial detail could be obtained by a simple interpolation of the 10' grid scale changes to a finer spatial resolution (5 km x 5km) and then by combining these interpolated changes with observed baseline information at that finer resolution. This approach is termed 'unintelligent' (by Hulme and Jenkins, 1998) because no new behavioural insight into the sectoral indicators is added that goes beyond the 10' grid scale changes and because the basic spatial patterns of the current indicators are assumed to remain largely unchanged in the future. However, more sophisticated statistical downscaling methods are computationally demanding and would likely lead to unacceptable runtime issues within the IAP.

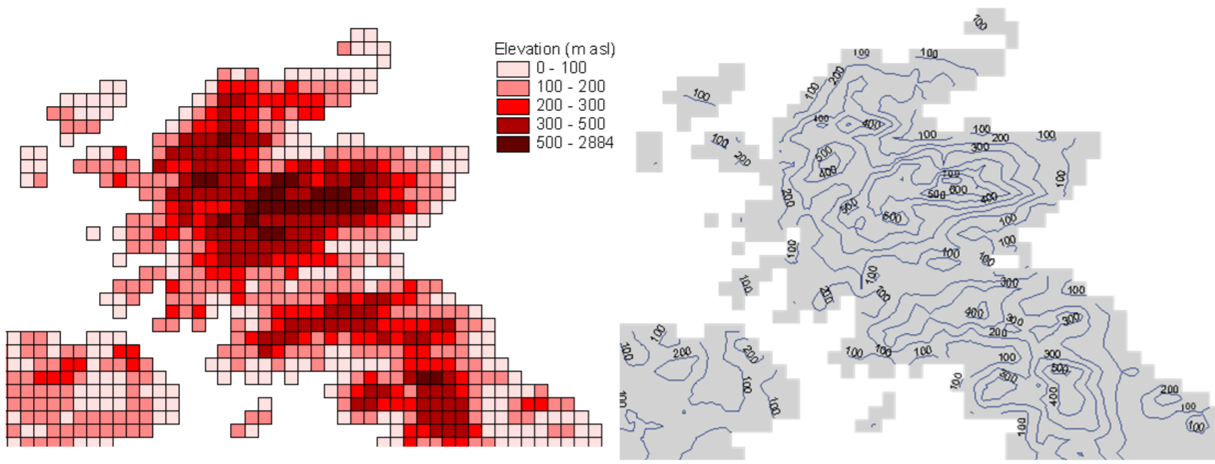

Figure 7: Illustrative example of the effect of interpolation to remove pixelated output.

Approach 3: Enabling variable input data spatial resolution

Given the scale that some adaptation occurs, the minimum spatial scale in Figure 6 (10' x 10') might not be adequate for some stakeholders. An alternative approach is therefore to change the spatial resolution of some of the input datasets as the user changes from the European to the regional case study. A spatial resolution of 5km x 5km is likely to be the minimum scale possible, given the limitations of available climate change scenarios and the spatial credibility of socio-economic storylines and data sources. For the Scotland case study, such a change in input and output resolution would lead to an approximate six-fold increase in the number of spatial units (Figure 8). However, there are potential challenges with such an approach, including applicability of some of the meta-models at this scale and availability of datasets (involving cost and IPR considerations). We are currently contacting some of the Scottish stakeholders to explore their expectations in terms of spatial resolution.

10' grid (Scotland ~ 458 cells)

10km x 10km grid (Scotland ~700-800 cells)

5km x 5km grid (Scotland ~3000 cells)

Figure 8: The effect of changing input data spatial resolution for the regional case study.

Approach 4: Enabling variable clustering of the existing input data

Clustering is a method in which clusters of objects are made that are similar in characteristics, and which can be simulated by the meta-model using a single set of data. For the purposes of land-use modelling at the 10'x10' scale, clustering will be used to aggregate the disparate soils within the individual cells into agro-climatic clusters to reduce the number of discrete entities to be computed from the approximately 23,000 grid cells to around 2,500 clusters. In this way highly heterogeneous 10'x10' grid cells may have proportions of their area allocated to as many as 23 clusters spanning Europe depending on the nature and areas of the cell's constituent soils. Whereas, very homogenous areas may have many adjacent 10'x10' grids in the same cluster. If the user wants to see results at finer resolution then the resolution of the clustering algorithm could be increased.

Clustering does not necessarily change the scale of the inputs or the outputs to the meta-models, but can change the level of spatial detail within the inputs by aggregating (to differing levels) areas with similar properties. At its most extreme, the effect of clustering is to reduce the internal variability from full variability (where the number of clusters is the same as the maximum number of grid cell and property combinations) to no internal variability where Europe is treated as a single lumped combination of properties. For example, three important variables when modelling crop yields are the available water content of the soil (Soil AWC), temperature and rainfall. These vary across grid cells, so Table 1 shows an illustrative example whereby 11 combinations of these three properties are clustered into 2, 3, 6 and 11 clusters.

In the context of the CLIMSAVE IAP, a relatively high level of clustering of input data might be used when viewing outputs at the European scale; a lesser level of clustering when viewing regions of Europe; and with no clustering in the regional case study.

Table 1: Illustrative example of the effects of clustering three variables.

Soil AWC	Temperature	Rainfall	Cluster			
50	7.5	800	1	1	1	1
60	8.6	700	2	2	5	2
45	7.5	600	1	3	3	3
33	7.6	700	1	3	4	4
60	8.9	710	2	2	5	5
45	7.5	1300	1	1	6	6
55	7.7	678	1	1	1	7
67	7.9	734	2	2	2	8
66	8.1	1000	2	2	2	9
61	8.2	777	2	2	2	10
71	7.5	888	1	1	1	11
Number of clusters			2	3	6	11
			Measure of internal cluster variability			
			0.35	0.31	0.15	0

Given the iterative development of the CLIMSAVE IAP through the duration of the project, based on the desire to take stakeholder feedback into account, the adoption of the multi-scale approach to meta-model application within the platform has yet to be finalised. However, the initial prototype IAP will include variable viewing scales and variable clustering of the existing input data.

Concluding remarks

Work Package 2 has made good progress within this first period, defining the specification of the web-based platform and the meta-models and producing initial versions of the meta-models. The focus of activity within the next phase is to improve the process representation of the meta-models and to complete their implementation within the Platform (D2.3), ready for testing of the prototype IA Platform in the summer of 2011 (M2.2).

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