UNIVERSITATEA POLITEHNICA BUCUREȘTI
FACULTATEA DE AUTOMATICĂ ȘI CALCULATOARE
DEPARTAMENTUL DE CALCULATOARE

TEZĂ DE DOCTORAT

Integrated software platforms for the study of climate change effects

Platforme software integrate pentru studiul efectelor schimbărilor climatice

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BUCUREŞTI 2019

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ABSTRACT

Una dintre tendințele societății contemporane este schimbarea, fie ea la nivel politic, social, cultural sau industrial. Această direcție de schimbare a fost transferată lent către mediul înconjurător și, astfel, către elemente din natură. Prin urmare, una dintre cele mai importante probleme cu care se confruntă societatea în prezent este schimbarea climei. Deși există din ce în ce mai multe eforturi și directive în sensul încetinirii și opririi acțiunilor umane care influențează schimbările climatice, suntem încă în pericol de a fi puși în fața unor situații extreme. Apare astfel nevoia existenței unor instrumente software pentru a cuantifica legătura bidirecțională dintre influența umană și echilibrul sistemului natural. Acest lucru determină necesitatea de a dezvolta instrumente integrate de evaluare, inovatoare, care să permită atât persoanelor cu putere de decizie, cât și publicului larg să aibă acces la informații științifice relevante și credibile privind schimbările climatice. Această teză prezintă două platforme care analizează impactul schimbărilor climatice asupra unei suite de sectoare cheie care interacționează și sunt interconectate prin intermediul resurselor, precum: pădurile, sectorul urban, utilizarea terenurilor, apa, inundațiile, agricultura și biodiversitatea. Acestea sunt platforme disponibile online, una cu răspuns rapid și celălaltă cu răspuns întârziat, care simulează efectele schimbărilor climatice la nivel multisectorial, permițând, de asemenea, explorarea unor strategii de adaptare. Rezultatele prezentate la sfârșitul capitolelor 3 și 4 confirmă și validează modelele integrate în cadrul platformelor. Noutatea introdusă de ambele platforme constă în a oferi o imagine de ansamblu care cuprinde interacțiunile dintre sectoare importante, în locul unei imagini înguste și izolate a fiecărui sector în parte.

One of the general characteristics of contemporary society is change, be it at political, social, cultural or industrial level. This changing trend has slowly been passed to the surrounding environment and thus to the natural elements. Therefore, one of the most important problems that society is facing nowadays is climate change. Although there are increasingly more and more efforts and directives in the sense of slowing and stopping the human actions that are causing climate change we are still in danger of facing extreme situations. Having this aspect in mind, a prominent need for software tools to quantify the bidirectional link between human influence and the balance of the natural system has emerged. This raises the need to develop innovative integrated assessment (IA) tools to allow both decision-makers and the general public to have access to relevant and credible scientific information on climate change. This thesis presents two platforms that analyze climate change impact on a multitude of important key sectors that interact and are interconnected through their sharing resources, such as: forest, urban, land use, water, flooding, agriculture and biodiversity. They are online platforms, one with fast and the other with delayed response, that simulate the effects of climate change at a multi-sectorial level, also allowing the exploration of adaptation strategies. Results presented at the end of chapters 3 and 4 confirm and validate the models integrated within the platforms. The novelty introduced by both platforms consists in offering a big picture that comprises the interactions between important sectors rather than a narrow and isolated image of each sector.

ACKNOWLEDGMENTS

Firstly, I would like to express my sincere gratitude to my advisor

Prof. Dr. Ing. Florica Moldoveanu

for the continuous support of my PhD study and related research, for her understanding, patience, motivation, and immense knowledge.

I would also like to thank the rest of my thesis committee: **Prof. Dr. Ing. Alin Moldoveanu et. al.** for their encouragement and insightful comments.

I would like to thank my husband **Octavian Rinciog** for his support, patience and understanding without which I would not have succeeded in completing this project.

My deepest gratitude goes to my colleague and collaborator **George Cojocaru**, whose support and help I have constantly relied on and with whom I worked side by side in order to conceptualize and develop the notions elaborated in this thesis.

I thank all my colleagues in **EU CLIMSAVE** and **IMPRESSIONS** research projects with whom I managed to carry out the research, development, implementation and testing activities of the proposed methodologies presented in this thesis.

The work on this thesis was partially funded by:

- Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU 187/1.5/S/155420.
- European Commission Seventh Framework Programme, Contract Number: 244031 (http://www.climsave.eu)
- European Union’s Seventh Programme for research, technological development and demonstration under grant agreement No 603416 (http://www.impressions-project.eu/)

1 INTRODUCTION

1.1 Context

Usually, the climate change is understood as global warming, meaning the rising of mean temperature. However, in the last years, the climate change manifests not only by the alteration of mean temperature, but also by the increasing of extreme weather events, changes in the type and amount of precipitation, habitat change and many others. Unfortunately, the effects of these perturbations extend to the socio-economic sectors, the link between them and the climate sector being a tight one. In the study developed by International Panel on Climate Change (IPCC) in 2014 [**4**], some of the 'proven effects' of climate change include frequent and intense droughts, floods, changes in food supply, decreased crop yields, adverse health effects, degradation of habitats and animal species extinction.

1.2 Problem

Past experience shows that living organisms possess an extraordinary ability to adapt in relation to environmental changes. The main condition to maintain this coping capacity is for climate change to occur at periods of centuries or even millennia. The problem with the current trend of climate change is that it occurs in short periods, duration being limited to a number of years. The motivation to act in accordance with climate change shouldn’t necessarily be found in what mankind has seen before, but in what existing scientific models predict for the near future. However, the magnitude and speed of climate change has a significant impact, which in time will threaten the sustainability of surrounding systems.

Those responsible for decision making do not take into consideration very often future climate scenarios, as complete information that takes into account matters like cross-sectoral interactions, interconnection of climate and socio-economic scenarios, existing vulnerabilities and available possibilities of adapting, is scarce and available in scientific formats that are not easy to understand. This is also due to the fact that stakeholders find it difficult to quantitatively assess climate impacts across sectors.

1.3 Objectives

Therefore, a limitation if not total cessation of human activities proven to be harmful to the environment is required. Another step to undertake in this process is the implementation of preventive measures and adaptation to climate changes. For all these to be achieved, it is necessary to provide stakeholders, decision makers and authorities with relevant scientific and real information in order to reduce climate risks. The solution identified to be the most effective is an integrated assessment (IA) [**32**] of existing knowledge which is directly or indirectly related to the environment. Because most often stakeholders are provided with the results of these evaluations without any possibility for them to influence the assessment process or the considered scenarios, the idea of a rather interactive evaluation platform emerged as being a more proper approach.

Tools that can assess the effects of complex combinations between climate change and socio-economic variables and possible adaptation options are scarce [**51**] and unavailable to the wide public. Therefore, there is an increasing interest for developing integrated assessment platforms to meet the needs of decision makers by providing relevant scientific information that they might consider in the process of decision making.

1.4 Proposed solutions

The current thesis brings into attention the implementation of two integrated assessment platforms, in which the author of the thesis had important contributions: CLIMSAVE IAP (Integrated Assessment Platform) [**55**], an interactive web platform developed within the FP7 EU funded CLIMSAVE research project and IMPRESSIONS dIAP (dynamic Integrated Assessment Platform) [**61**] developed within IMPRESSIONS FP7 European research project.

Having as a starting point the ATEAM project [**36**], the two platforms developed and detailed in this thesis are by far some of the best tools to be used by stakeholders and decision makers to understand the negative impacts that people may have on the environment and vice versa.

CLIMSAVE IAP (Integrated Assessment Platform – [**55**]) is an interactive web platform that can be easily used as a large-scale e-learning tool. CLIMSAVE IAP is a participatory IA platform, which allows users to study an extensive number of impact indicators in key sectors such as agriculture, land use, biodiversity, coasts, forests, water and urban. These indicators provide people the opportunity to understand how climate change may affect various life sectors. The platform treats the effects of climate change at European level and also locally in a Scottish case study. However, in this thesis my focus is on the European level platform. Advantages such as large accessibility, fast response time and ease of use make this platform a perfect candidate to improve people's quality of life by raising awareness on the harmful effects that humankind might have on the environment through its actions and decisions.

IMPRESSIONS dIAP [**61**], built starting from its predecessor - CLIMSAVE IAP, brings into attention the effects of critical climate scenarios by simulating their impacts on natural resources and society during the entire 21st century. The integrated assessment platform encompasses a number of uni-sectorial meta-models that simulate the effects of climate change for Europe during 2010-2100. The meta-models within the platform are representative for the following key sectors: urban, water, agriculture, forests, coasts, land use and biodiversity. The simulations that are possible to run using the platform enable users to meet potential critical situations that they could potentially face, giving them access to the adaptation variants that could be adopted in order to avoid these disastrous scenarios (high-end scenarios). This platform aims to help stakeholders and those responsible for decision making and thus potentially improve the quality of life on the medium and long term.

1.5 Results

The results presented at the end of chapters 3 and 4 highlight the possibility of exploring both predefined and user customized scenarios either combined or simple, in both platforms. The results obtained running both customized and predefined scenarios confirm and validate not only the meta-models but also the scenarios integrated in CLIMSAVE IAP and IMPRESSIONS dIAP.

1.6 The author's scientific publications in connection with the thesis

During my PHD study years I have published a series of articles in journals and conferences as first author or in collaboration with other colleagues. This thesis is based on these articles and the research reports developed during my PHD study years. The articles are presented below:

Articles in ISI indexed journals:

1. Brown C, Brown E, Murray-Rust D, Cojocaru G, **Savin C**, Rounsevell M , "Analysing uncertainties in climate change impact assessment across sectors and scenarios," *Climatic Change (Q1 rank, impact factor 3.537)*, vol. 128, no. 3-4, pp. 293-306, February 2015. WOS:000348802400010.

2. Harrison PA, Dunford R, **Savin C**, Rounsevell MD, Holman IP, Kebede AS, Stuch B , "Cross-sectoral impacts of climate change and socio-economic change for multiple, European land-and water-based sectors," *Climatic Change*, vol. 128, no. 3-4, pp. 279-292, February 2015. WOS:000348802400009.

3. Wimmer F, Audsley E, Malsy M, **Savin C**, Dunford R, Harrison PA, Schaldach R, Flörke M. , "Modelling the effects of cross-sectoral water allocation schemes in Europe," *Climatic Change*, vol. 128, no. 3-4, pp. 229-244, February 2015. WOS:000348802400006.

4. Kebede AS, Dunford R, Mokrech M, Audsley E, Harrison PA, Holman IP, Nicholls RJ, Rickebusch S, Rounsevell MD, Sabaté S, Sallaba F , Sanchez A, **Savin C**, Trnka M, Wimmer F. "Direct and indirect impacts of climate and socio-economic change in Europe: a sensitivity analysis for key land-and water-based sectors," *Climatic change*, vol. 128, no. 3-4, pp. 261-277, February 2015. WOS:000348802400008

5. **Savin** C, Moldoveanu F, Moldoveanu A , "Modelling Climate Changes Through Delayed Response Platforms", Scientific Bulletin of UPB, series C, vol. 81, no. 1/2019, pp. 13-24

Articles in ISI indexed conference proceedings:

6. **Savin C**, "Embedding Sectorial Models in an Integrated Platform for Assessing Climate Change Impacts," in Proceedings of the 9th IEEE European Modelling Symposium on Computer Modelling and Simulation (EMS), Madrid, October 2015, pp. 37-42. WOS:000411862000003

7. **Savin C**, Moldoveanu F, Moldoveanu A , "Simulation and visualization tool to explore the impacts of complex and cross-related environment changes" in

Proceedings of the 11th International Scientific Conference on eLearning & Software for Education, Bucharest, April 2015, pp. 573-580. WOS:000384469000083

8. **Savin C**, Cojocaru C., Moldoveanu F, Moldoveanu A , "mLearning application for ecosystem services assessment on site," Proceedings of the 12th International Scientific Conference on eLearning & Software for Education, Bucharest, April 2016, vol. 1, pp. 386-391. WOS:000385395900055.
9. **Savin C**, Cojocaru C, Moldoveanu F, Moldoveanu A , "Modelling Climate Change Impacts using online Platforms" in Proceedings of the 13th International Scientific Conference on eLearning & Software for Education, Bucharest, April 2017, vol. 2, pp. 515-522. DOI: 10.12753/2066-026X-17-158.

1.7 Thesis structure

The thesis contains five chapters and 4 annexes. It starts by discussing the issue of climate changes and the need to develop tools to simulate their impacts, continuing with the study of existing solutions. The development of methodologies and their implementation in two multi-sectoral climate change assessment platforms are described. There are presented the results obtained by simulations using these platforms and how they can solve the initial problems.

The “State-of-the-art” chapter describes how the quantification of the effects of climate change has been done so far, giving examples of existing methods and models.

The third and the fourth chapters present the two platforms that were developed in the framework of the European projects - CLIMSAVE and IMPRESSIONS, through which climate change cross-sectorial assessments are made available. Each of the two chapters is structured in six main subsections. The first four subsections refer to the research methodologies of the projects and how they rely on stakeholder elaborated scenarios. Details concerning new methodologies and the description of the climatic and socio-economic scenarios integrated within the platforms are provided. In the fifth section (“Platform design and implementation”) of each chapter I describe the design and implementation of the rapid response platform (CLIMSAVE IAP) and the delayed response platform (IMPRESSIONS dIAP). I describe how to integrate the scenarios mentioned in the previous section, the meta-models, but also the data flow and links established between these meta-models, taking into account the input and output data of each meta-model. I also present details about the technologies used for each platform, how data and the mathematical meta-models are organized. The last section (“Results”) presents some results obtained by running the implemented platforms, namely quantification of the effects of climate change.

The “Conclusions and future work” chapter emphasizes my personal contributions, namely the theoretical research and studies that I have undergone in the methodology set-up processes of both platforms, but also the practical actions that I undertook in the design and implementation of the two platforms through which information technology was used to communicate the effects, vulnerabilities and the possibilities of adaptation of the environment to climate change.

2 STATE-OF-THE-ART

In the context of climate changes there is a need for systems that provide stakeholders and decision-makers the possibility to simulate and visualize a number of representative parameters from key sectors, considering the expected climate change. This simulation can be done at the level of only one sector, but according to Rotmans [**42**] the evaluation of these parameters has to be designed in an integrated interconnected sectorial system in order to grasp any links between the sectors that are being considered. Also, in this study Rotmans grouped these evaluation tools under the generic name of IA (Integrated Assessment) system.

The first integrated assessment models appeared in the 1980s, addressing the topic of acid rain, its causes and its negative effects [**2**]. In time, scientists and experts have noted the potential of these models, applying them in more and more areas, climate change being one of them. Thus, one of the first IA models addressing the climate change problem itself appeared in the early 1990s and is known as the DICE model (Dynamic Integrated model of climate and the Economy) [**29**]. It was designed as a loop that takes into consideration global factors such as emissions, climate change, damages but also economic factors.

An existing drawback of IA models is the fact that they do not take into account the response and reaction of persons that come in contact with the results provided by models, the communication between them and models being unidirectional. As in the case of a learning process, the communication between models and users should preferably be done in both directions, the purpose being not only an educational one, but one that answers to people's sensitivity. Current trends in the area of IA models consist of a participatory development in order to be customized and calibrated according to the applicability of the model. These models are called PIA models (Participatory IA [**43**]) and have been used in recent years. Therefore, in order to meet these models a new approach has been followed, namely one that transforms the qualitative data provided by stakeholders into quantitative ones to feed the existing models (‘story-and-simulation’ approach [**24**]). Also, as most of the IA models do not have time constraints, their execution takes very long periods, thus limiting the interaction with stakeholders. As alternatives to these models, PIA models have as a main requirement the implementation of a user interface allowing stakeholders to interact with the model itself, increasing the transparency of the model and promoting the link between academia and user communities in a continuous learning process.

This chapter presents state-of-the-art literature together with the available tools and platforms that refer and propose solutions on climate change. I am focusing mostly on research projects done in Europe because it is a leading actor in the climate change field with a high interest in the climate change impacts, but the research interest in this field is spread on the whole globe: New Zealand (CLIMPACTS project), South Korea (MOTIVE project), Taiwan (TaiCCAT research program), Japan, Australia and USA.

2.1 MEDIATION - Methodology for Effective Decision-making on Impacts and AdaptaTION

MEDIATION [**39**] is a FP7 European project developed between 2007-2013 which put in the spotlight climate change and population’s vulnerability. The project proposes a thorough study of these changes since full attention of researchers until this project was put on reducing the greenhouse effect. At that time there was little technical and scientific information about other aspects of climate change impacts and vulnerability. The project’s aim was to analyze the context at that time and to develop new metrics and methods on the impacts, vulnerabilities and adaptation possibilities. MEDIATION proposed to develop a methodology and an interactive and flexible platform for persons responsible for decision making in order to be informed and aware of the true impact of climate change.

According to this project, rapid climate change means adapting the society to a number of hazards, in most cases characterized by many uncertainties. MEDIATION Adaptation Platform meets this need by specifying actions to be taken in order to avoid them.

MEDIATION provides stakeholders with a toolbox (*Figure 2.1*) through which they are informed about the methodology, methods and existing tools on a variety of issues (Impact Analysis, Valuation, Scenario Analysis, Treating Uncertainty).

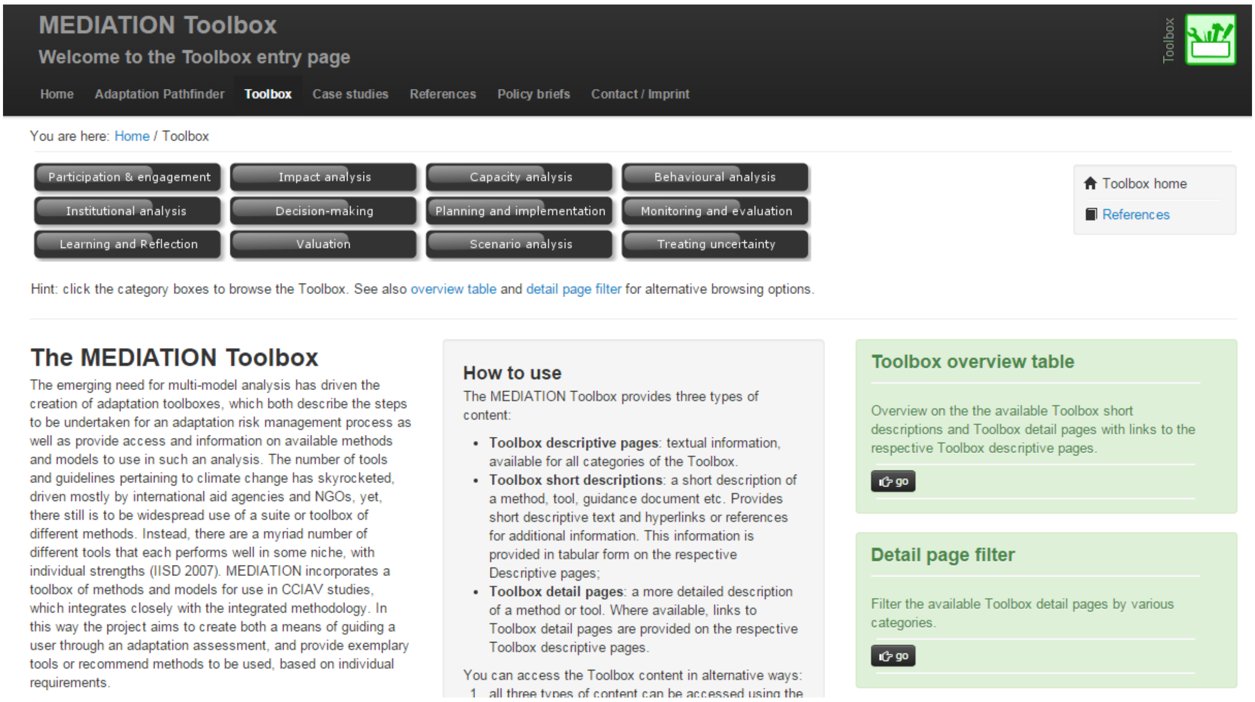


Figure 2.1 MEDIATION Toolbox[1]

[1] http://www.mediation-project.eu/platform/toolbox/toolbox.html

The tool provided by MEDIATION is called MEDIATION Adaptation Pathfinder (*Figure 2.2*) which offers interactive access to a set of advices on impacts, vulnerability and adaptation possibilities of climate change. The novelty compared to other platforms of this type is how various available approaches are integrated in a coherent and integrated adaptation platform. Also, this platform provides assistance on what methods to be used in the existing climatic conditions. Such decisions are based on certain choices in certain key points of the adaptation process. In this platform this flow is presented under the form of decision trees derived from a series of case studies from different parts of Europe. Decision interest points were organized in an adaptation learning cycle that covers 5 stages:

1. identifying vulnerability and impacts;
2. identifying adaptation measures;
3. appraising adaptation options;
4. planning and implementing adaptation;
5. monitoring and evaluation;

In each of these steps one entry point is present through which the user can enter deeper into that stage of adaptation. During the process, if there is an interest in a certain adaptation measure, there are links that redirect the user to a detailed section about it in the Toolbox. However, this decision model is idealistic and organized. In reality the adaptation process is not linear, even more, it is chaotic and does not respect a linear or cyclical structure.

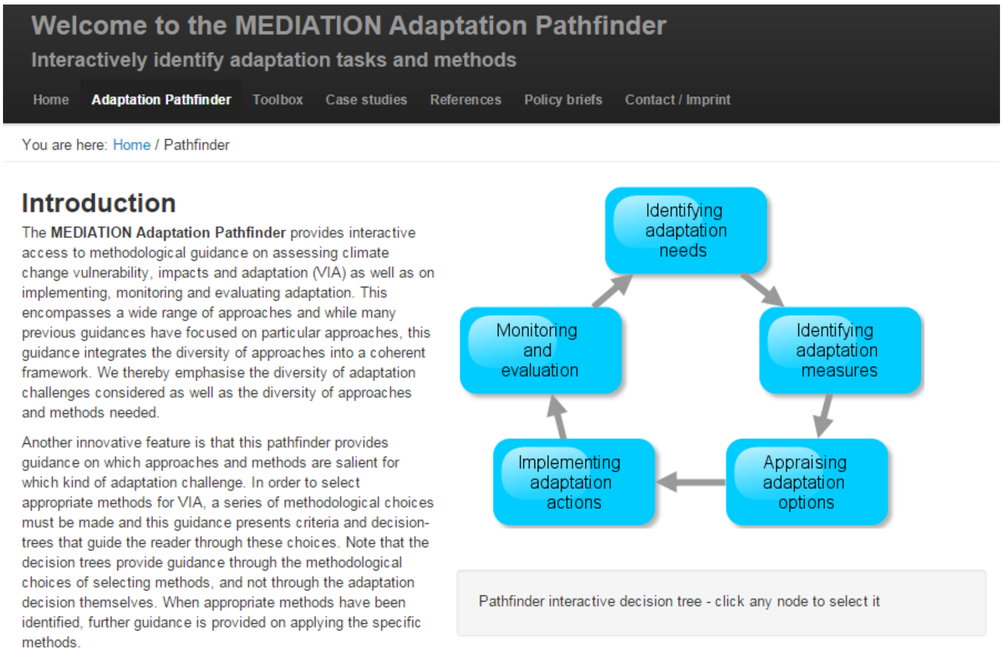


Figure 2.2 MEDIATION PathFinder[2]

[2] http://www.mediation-project.eu/platform/apf_entry/entry_point.html

2.2 ClimateCost

ClimateCost [**37**] is a FP7 European Project that was developed between 2008 and 2011 and proposed to develop an economic analysis on the costs brought in by climate change. The project wanted to fill in the gaps on the economic imbalance caused by climate change by analyzing research projects developed at that time and by thorough economic analysis.

The areas of interest covered by the project are:

- Long-term targets and mitigation policies.
- Costs of inaction (the economic effects of climate change).
- Costs and benefits of adaptation.

The results are provided for each European country, as well as for China and India. Like most other European projects ClimateCost aimed that the information extracted, developed and supplied to be used at political and decision-making level.

Thus, the main objectives of the project were:

1. Identification and development of climate, socio-economic and adaptation scenarios which capture best climate changes;
2. Quantification in terms of physical and economic effects of climate change using GIS maps;
3. Evaluation of potential economic costs in disastrous scenarios;
4. Upgrading costs introduced by the effort to reduce greenhouse effect;
5. Development of integrated models for integration analyzes;
6. Aggregation of information and results as well as the distribution and dissemination to stakeholders;

In terms of the output visualization, the results were synthesized as scientific reports, any interactive interface to view those, not being available. This approach could cause a lower interest of users as compared to other projects that offer navigation and visualization tools for results.

2.3 MOTIVE - MOdels for AdapTIVE forest Management

MOTIVE [**40**] is a FP7 European project that was developed between 2009 and 2013 and was intended to study existing and potential adaptation strategies for changes that occur at climate and soil level. The focus of this project is directed to the influences and impacts of these changes on forests and services provided by them. Thus, one of the main questions that MOTIVE tries to answer is "What are the species of trees that can adapt most easily to environmental changes?". The project focuses on assessing the negative consequences that environmental changes have on a number of European species, aiming the dynamics of forests.

MOTIVE tries to assess coping strategies to counterbalance the effects of environmental changes. This strategy was made possible through extensive study of a series of case studies undertaken in: North Karelia (Finland), Kronoberg (Sweden), Wales (UK), South-East Veluwe (Netherlands), Black Forest (Germany), Montafon Valley (Austria), Prades (Spain), Chamusca (Portugal), Panagyurishte (Bulgaria), Carpathians (Romania), covering most regions of Europe bioclimatic. Possible scenarios start from the most optimistic ("no major change for forest ecosystems') to the most pessimistic ("extreme deterioration of the growth conditions for trees").

Performed assessments and studies were developed using the existing sectorial instruments having as conclusions the following:

1. In the UK the possibility with greatest chances of adapting to climate change is the diversification of tree species.
2. The Netherlands will preserve the same management as before, with a steady monitoring of the strong links between climate and the forest sector.
3. Adaptation measures are inherent in terms of the German case study, one of the main sectors in which adaptation is needed is the existing living species from forests.
4. For Austria was concluded that adaptation measures (species composition, spatial structure of forests measures, management intensity and game management) must be taken in order to obtain the desired effect.
5. In the case of Spanish study, the biggest threats come from potential droughts and dry periods. Thus, the main limitation of adaptation is the economic sector, forest management operations being very expensive.
6. In Portugal the main climate threat are fires that appear in summer given the arid climate. This can lead to a reduced production of cork oak. As adjustment, possible fire prevention measures, increasing forest density and faster harvesting are considered.
7. Romania expects the number of conifer species to decline, influenced by the extensive deforestation in recent years. Changing tree species will have a long term effect on the total volume of biomass.

As a general conclusion, it is expected an expansion and a rise in forest species density in Northern Europe (*Figure 2.3*), while the south will have to adapt new species of trees. So, it is advisable that each country and region should consult likely future climate scenarios in that region and adapt or replace their current forest species by species resistant to the projected climate conditions. This proposed adaptation method will be different from one region to another given the fact that climate change has an uneven influence for different regions of Europe. MOTIVE results are presented as theoretical documentation based on sectorial models existing at the starting point of the project (ex: Portuguese self-decision support system [**59**]).

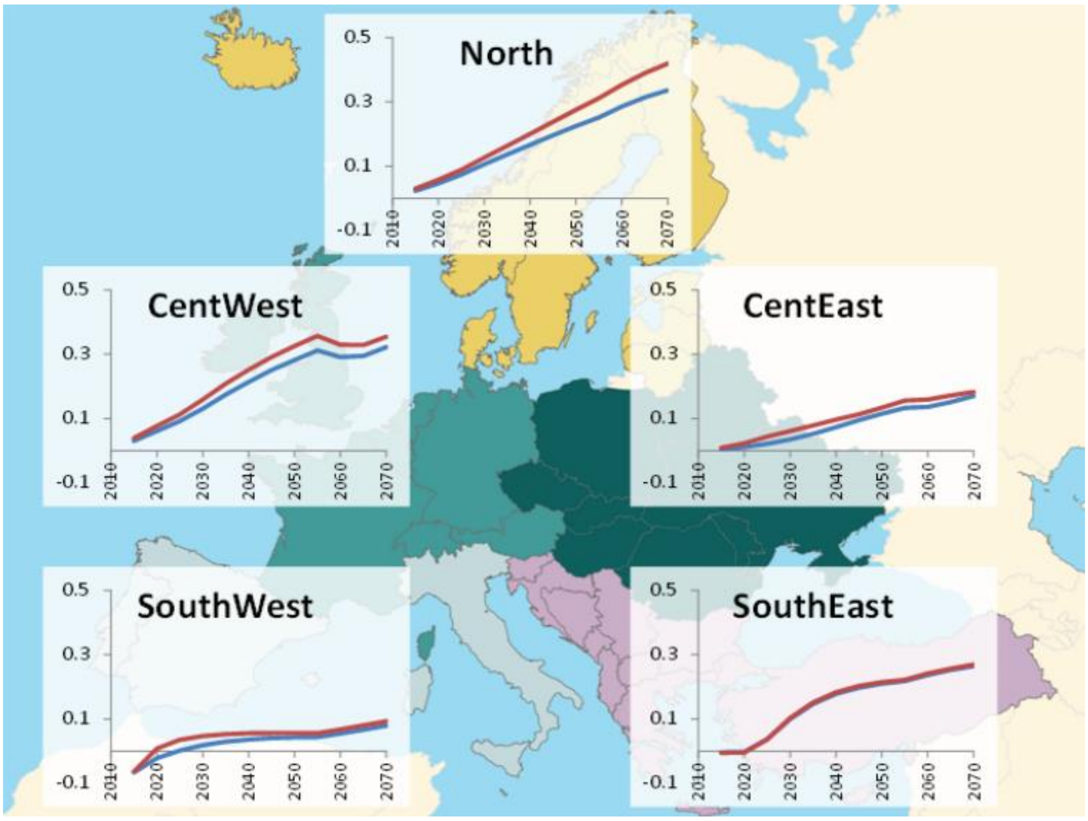


Figure 2.3 Forests adaptation capacity in response to climate changes[3]

2.4 NeWater - New Approaches to Adaptive Water Management under Uncertainty

NeWater [**31**] is a FP6 European project developed between 2005 and 2009 which put in the spotlight the possibilities of watershed adapting. The project has identified key elements in water management system and focused on their translation into adapted elements to the new conditions:

- Integration at sectorial level
- Water Management System
- Infrastructure
- Stakeholder involvement
- Information management

Dilemmas such as floods, droughts, water quantity vs. water quality or maintaining aquatic biodiversity are some of the issues hydrologists face in their attempt to keep water sector in equilibrium. Even more, climate changes bring more uncertainty to those listed above.

[3] https://cordis.europa.eu/result/rcn/145880_en.html

NeWater has proposed to meet these challenges using the concept of integrated water resource management (IWRM).

Among the main objectives of the project are the following:

- Develop a research platform for managing watershed adaptation, integrating concepts of environmental science, engineering, social environment etc.
- Apply project knowledge on as many European water basins as possible.
- Adaptation approaches should also consider poverty alleviation, gender awareness and health planning.
- Develop tools for evaluating adaptation.
- Identification and classification of the IWRM uncertainty.
- Identification of negative influences from external shocks, impacts and vulnerability trends.
- Develop a toolkit and a guidance tool for practitioners and stakeholders to implement adaptation methods.
- Share impressions, experiences and innovations in dialogues, publications and conferences

The link between scientific research and its application in real life was made in NeWater through case studies organized at river basin level: Rhine, Elbe, Guadiana, Tisza, Amudarya, Nile and Orange. In terms of the results, they are synthesized in the form of scientific works available to anyone interested.

2.5 ATEAM – Advanced Terrestrial Ecosystem Analysis and Modeling

ATEAM [**36**] is a FP5 European project that was developed between 2001 and 2003 and aimed to assess the risks induced by global environmental change on natural ecosystems. Changes in climate, soil or air can have negative impacts on these natural systems that provide vital services to individuals and society (drinking water, agricultural products, recreation services). ATEAM has shown a growing interest in trying to defend global change and preserve the natural balance that we all benefit from. Thus, in this project was developed a tool designed to help stakeholders in their decision-making process and to promote maintaining ecosystem balance. The project also keeps under observation social vulnerabilities induced by global changes.

ATEAM main objectives are as follows:

- Developing a platform for modeling changes in Europe's terrestrial ecosystems at regional scale;
- Indicator development regarding the adaptive capacity of society;
- Developing a set of scenarios for the climate, socio-economic sector, soil, pollution levels, atmospheric composition by 2100;

- Developing a communication channel with stakeholders, which ensures the applicability of results in the management of natural resources;
- Providing maps that highlight vulnerable sectors of global change;
- The platform developed by ATEAM is an offline tool called ATEAM Vulnerability Mapping Tool that can be downloaded from [**36**] (*Figure 2.4*). For its development, a suite of existing ecosystem models were run in the fields of biodiversity, agriculture, forestry, hydrology and carbon sequestration. These models were run on future scenarios designed in the project, the results being integrated in the instrument. This tool is available offline offering a digital atlas of maps created within the project as well as additional information and analysis. Results are available for baseline and 7 other climatic and soil scenarios, each of which can be viewed for 3 time slices (1990-2020, 2020-2050 and 2050-2080).

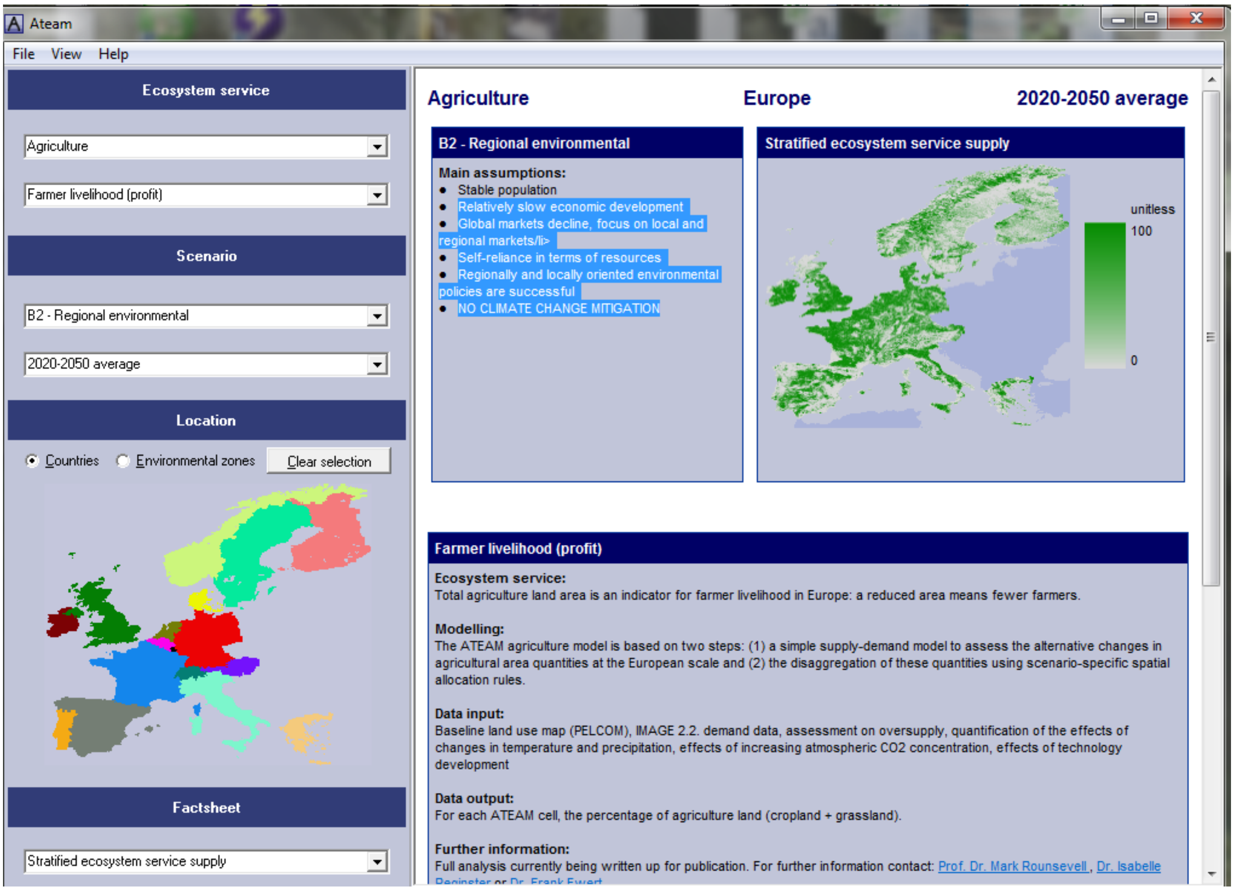


Figure 2.4 ATEAM Vulnerability Mapping Tool

Maps provided by the tool integrate helpful information for interpretation. The disadvantage of this approach is that the results are obtained in advance, the instrument actually providing only data visualization, integrating the results from several models. Also, the data obtained from considered sectors were obtained by running existing sectorial models without an explicit link between them. In this way the results of a sectorial model do not take into account the results of another dependent model.

The project concludes that most climate change and soil scenarios highlight major disruptions at European level. Although some of the results obtained can be considered positive impacts (increased agricultural and forestry area), most of them have negative consequences in terms of ecosystem services, which will reflect on society (low soil fertility, risk of fire). Therefore, ATEAM recommendation is that immediate actions should be taken by all stakeholders.

2.6 TESSA

TESSA [**34**] is a set of methods for assessing ecosystem services conceptually developed by a group of institutions including UNEP-WCMC (UN Environment World Conservation Monitoring Centre). This information flow assessment was developed to provide practical advice on how to assess and monitor ecosystem services. The toolkit helps users identify services that can be evaluated, the data needed to measure them, the methods or sources that can be used to obtain data, and how to communicate the obtained results in order to achieve biodiversity conservation.

Developing the information flow assessment started from the premise of finding a balance between simplicity and utility that can provide convincing information to decision makers and therefore, did not take into account the most advanced complex concepts in the ecosystem services field. The advantage of this approach is that it can be used by non-experts, providing yet robust scientific information.

Based on this information assessment flow of ecosystem services (*Figure 2.5*), a mLearning software tool [**45**] was designed and implemented. This tool enables both scientists and interested but uninitiated people to measure the benefits of nature biodiversity over humans.

To determine the type of application that can be implemented to meet the needs of the persons responsible for measuring and assessing ecosystem services, they were shown several versions of applications focusing on different properties, advantages and disadvantages that each of them has. Later I designed a questionnaire that helped deciding that a hybrid mobile application which combined e-learning properties with the mobility and the speed of an offline system together with the advantages of an Internet connection such as geolocation or access to other external sources is the best choice for potential users.

The survey answers have supported the idea of a mobile application. 104 people out of 131 respondents considered immediate data processing as one of the most important features that an application should meet.

From the point of view of the mobile platform, the application was designed and implemented for Android operating system, as when surveyed in late 2015 by IDC (International Data Corporation), this operating system was the most widespread of all mobile platforms, with a market share of over 82.8% [**62**].

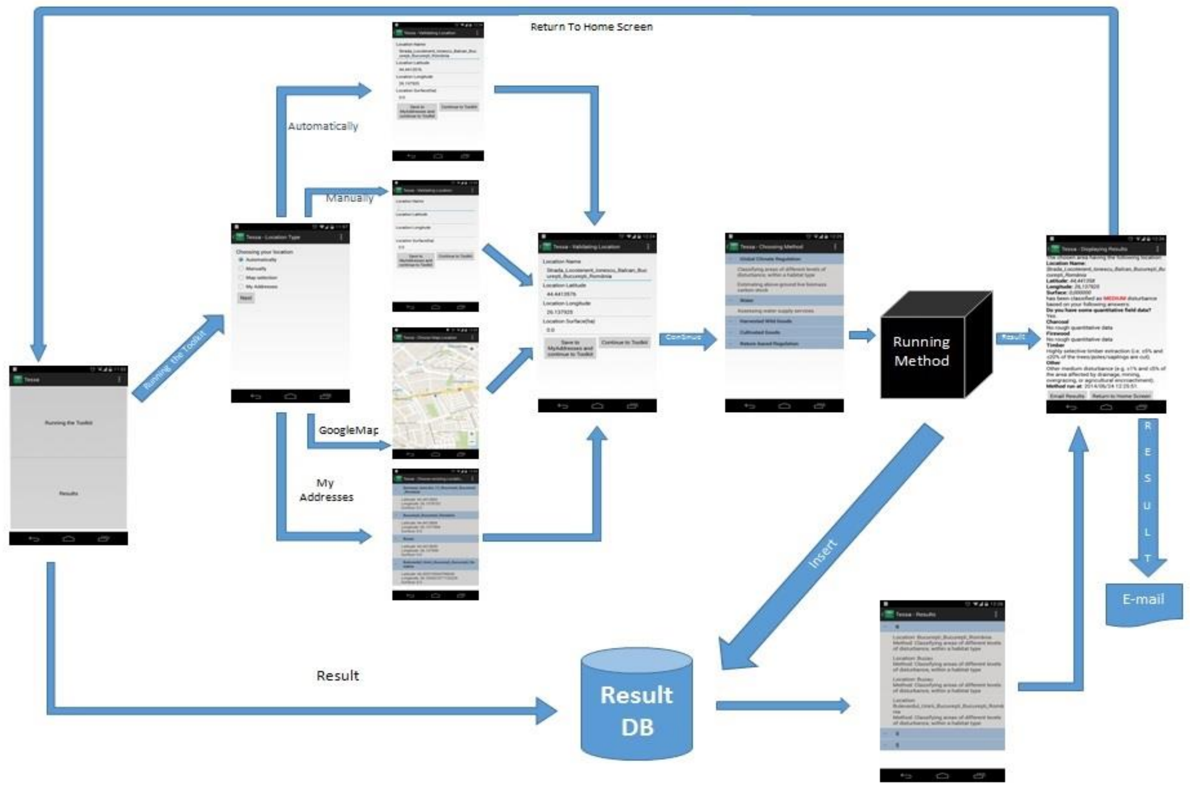


Figure 2.5 TESSA application workflow

The main functionalities taken into consideration for the mobile application, as were decided by its future users are: (i) geolocation, (ii) data input storing, (iii) results supply and saving.

The software tool for assessing ecosystem services is designed to improve the existent limited assessment and measurement techniques of ecosystem services by providing practical guidance to scientists on how they can identify the significant ecosystem services on a site, analyze the data needed for their measuring, methods or sources that can be used to get the data and how to communicate the results.

2.7 CLIMPACTS and SimCLIM

In the early 90's in New Zealand was developed CLIMPACTS [**23**], a model that analyses the impacts that climate change has on the agricultural sector of this country. The model followed three different approaches: one that analyses data at a national scale and provides spatial results and another two which explore data at a higher scale, namely at a regional and local level. The latter approaches offer both temporary (variations) and spatial results. These multi-scale spatial and temporal approaches were extended to generating climate change scenarios. At first the model itself was applied mainly to Australia. The core of the model was further modified for different sectors and regions and applied in different countries other than Australia. However, CLIMPACTS was available to a limited set of users as it was not accessible online.

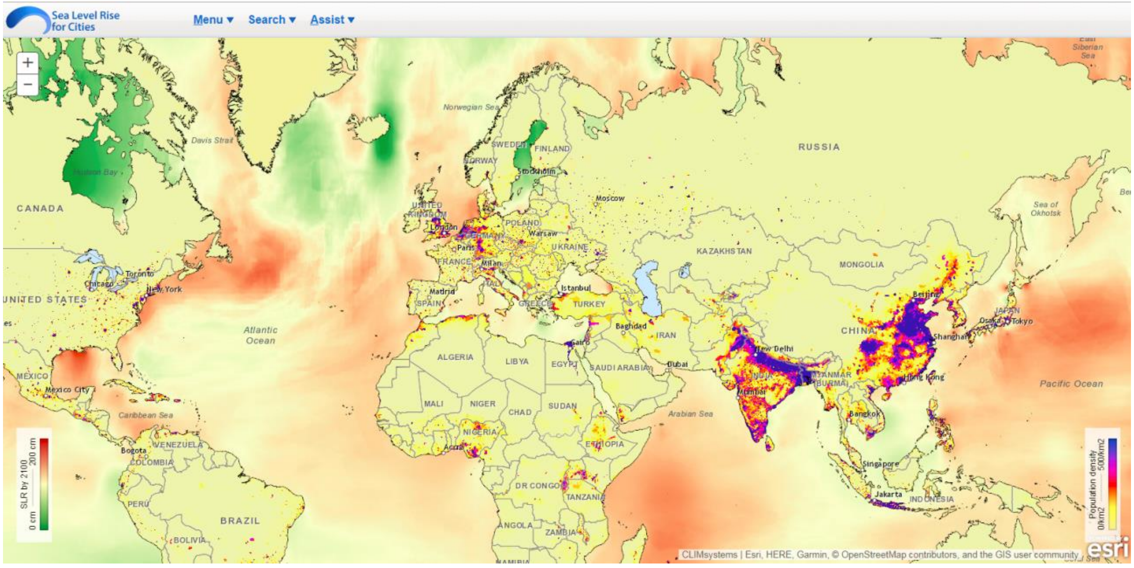


Figure 2.6 SimCLIM SLR for Cities Web App[4]

Based on the original CLIMPACTS, a company in New Zealand (ClimSystems) has developed a climate change risk assessment system. This solution (SimCLIM [**54**]) is a dedicated software which permits visualization of climate data and integrated model results such as: water balance and coastal erosion. The aim of SimCLIM was to develop the original CLIMPACTS model into a software tool that would give active support to evaluate the adaptation options for coping with climate change. SimCLIM was designed as a suite of tools, some of them available only for desktop use (SimCLIM Desktop, SimCLIM for ArcGIS) others available also online (SimCLIM SLR Web App, SimCLIM SLR for Cities Web App – *Figure 2.6*). All these tools combine different models in order to provide users credible spatial site specific scenarios with data for climatic indicators such as sea level rise (SLR).

[4] https://slr-cities.climsystems.com/

3 CLIMSAVE INTEGRATED ASSESSMENT PLATFORM

Although for a long time it was assumed that climate changes from recent decades have as a leading cause extreme natural phenomena such as volcanic eruptions, landslides, earthquakes, plate tectonics, explosions and unexpected cosmic phenomena, the last report [**4**] issued by the regulatory organization in the field - Intergovernmental Panel on Climate Change (IPCC) – confirms the major negative influence of human actions on the climate system. IPCC findings show that changes recorded since 1950 are unprecedented and are largely due to the direct or indirect intervention of humans on climate factors.

The issue of climate change is addressed by a number of researchers studying sectors such as water, soil, forests, agriculture, etc. CLIMSAVE IAP is a solution for the problem of interconnecting researches in these sectors. The methodology on which the platform is based uses climate and socio-economic scenarios and mathematical models defined by researchers from different sectors, as mentioned above.

Despite the large number of sectorial assessment models, platforms that offer the opportunity to put them together and integrate their results have long running times. Thus, it was a striking need to develop an interactive system that can provide stakeholders and competent authorities with relevant scientific information intended to be used in their taking decisions process by visualizing and simulating the impacts of climate change and also assessing the possibilities of adaptation.

CLIMSAVE IAP, one of the platforms implemented during my doctoral studies is described in this chapter and is available online [**55**], allowing stakeholders to assess the impact of climate changes and vulnerabilities in key natural and anthropogenic sectors such as agriculture, forests, biodiversity, water resources and the urban sector.

3.1 CLIMSAVE objectives and proposed methodology

The main purpose of the CLIMSAVE project was to deliver a research methodology that can assess the impacts and inter-sectorial vulnerabilities caused by climate change, as well as to propose viable adaptation solutions. This new methodology, materialized in the elaboration of a web platform (CLIMSAVE IAP), is based on methods, meta-models and datasets developed within the project. In order to achieve this goal, CLIMSAVE project had the following objectives:

1. Stakeholders integration in the elaboration of input data necessary to the platform in the form of climate and socio-economic scenarios;
2. Analyzing the political and governmental contexts in order to develop adaptation strategies;
3. Development of an integrated platform for assessing and simulating the impacts and vulnerabilities of climate change;
4. Scenario development;

5. Finding a solution to assess the financial effectiveness of the proposed adaptation measures;
6. Identification of regions with increased vulnerability using existing metrics in each sector taken into consideration;
7. Investigating the success rate of the proposed solutions;

3.2 CLIMSAVE features summary

- The CLIMSAVE project brings important contributions to the research side by simulating through the assessment platform the effects of climate change, proposing solutions to adapt to the impacts and vulnerabilities produced by them, using the assessment platform developed within the project.
- The interconnection of different sectoral meta-models allows stakeholders to see how their interactions can modify the effects of climate change.
- The integration of the socio-economic scenarios provides the user the option to simulate the impact of climate changes at the climate level as well as socio-economic level.
- The platform also allows stakeholders to explore adaptation strategies to reduce vulnerability to climate change, discovering where, when and under what conditions such strategies could help.
- Integration of user input in the context of climate change impacts is done through customized scenarios, which are consistent and plausible descriptions of the future.
- The CLIMSAVE IAP is a user friendly, interactive web-based platform, intended for free use and as a e-learning tool, allowing the study of an extensive range of impact indicators at European scale, based on a series of interactive climate and socio-economic scenarios. These scenarios were developed with the help of stakeholders who have been engaged in various stages of the project, starting from its inception.

The main features of the CLIMSAVE platform are:

- fast response times
- online availability [**55**]
- ease of use
- available at any time
- developed with the help of existing web technologies
- allows vast access for users in all areas, with academic and research preponderance
- online simulation of a large scale of impact indicators from a series of natural, social and economic key sectors among which: urban, water, agriculture, forests, coasts, land use and biodiversity
- offers people the possibility to understand and be aware of the disastrous effects that mankind actions may have on the natural environment, climate factors and ecosystem services
- integrates and interconnects a wide range of models from so different environmental sectors:

  - meta-modeling approach – meta-models are in fact the simplified versions of existing complex models
  - integration of 10 meta-models belonging to diverse sectors
  - meta-models are implemented as independent components that and can be replaced at any time with new or improved ones
  - meta-models have been designed and implemented in different research institutions. The modeling, implementation methods and their programming languages are different.
- the accuracy of the obtained results cannot be guaranteed, due to the meta-modeling approach, being rather a tool that complements complex models providing an overview of the impacts of climate change on a large number of sectors
- learning and e-learning tool by raising tomorrow's generation of decision-makers to be aware of the impact of climate change and the measures that can be taken to limit them

The CLIMSAVE IAP development process was iterative given that a number of changes were made due to the evaluation, responses and recommendations of stakeholders. Even more, the platform still suffers minor changes and improvements based on recommendations and assessments received from users and stakeholders.

3.3 Progress beyond state-of-the-art

3.3.1 Stakeholder involvement

CLIMSAVE has integrated stakeholders into the project and their involvement was an active one by developing the storylines of the socio-economic scenarios necessary for the assessment platform. Their involvement has been constant throughout the duration of the project by applying, testing and validating the research methodology proposed within CLIMSAVE. Stakeholders have directly influenced the development of the assessment platform by calibrating input data, helping to quantify the socio-economic scenarios, and evaluating common outcomes by sharing information mutually.

3.3.2 Adaptation options and policies

From the point of view of the adaptation measures taken at European level, they concern mainly the risk of floods. These measures are taken in order to better manage the emergency situations that may occur and to find a way to prevent them. In most cases situations are viewed unilaterally without taking into account the needs of other sectors or possible adaptation by applying changes in other sectors such as agriculture or ecosystems. CLIMSAVE assessed the existing adaptation methods and their implementation measures, also taking into account the different sectorial policies adopted. Stakeholders have also been involved in this assessment. Their perception of the proposed adaptation policies and their implementation is an important decision-maker on how their applicability in everyday life is beneficial.

3.3.3 Development of the integrated assessment platform

Although CLIMSAVE IAP is not the only existing integrated assessment platform, it brings novelties in both integrated sectorial models and platform facilities. Thus, the main features through which the platform innovates are bridging its interactivity by using web technologies with the possibility of studying the results obtained within the meta-models in real time, without the need for installing a separate software product. The platform's interactivity was also possible thanks to the simplified sectorial models that were integrated into the platform which allowed them to run in real time, allowing the user to view the results as soon as each individual meta-model had finished running.

The integrated meta-models can be replaced at any time with improved versions as long as they maintain the communication conventions established a priori for them. They were conceived to be independent software components following the idea of them being developed by separate entities, making it possible to easily integrate them and to have the possibility to identify and isolate the potential errors discovered in the testing and evaluation process executed by both developers and other stakeholders.

Another important feature of the platform is that multi-sectorial results are made available upon completion of the desired scenario, as the platform integrates a series of interconnected meta-models: urban, agricultural, coastal, water, forests and biodiversity. Thus, the platform simulates the impact of climate changes not only taking into account an isolated sector but a cumulus of sectors, taking into consideration the interactions between them and how indicators in a sector can decisively influence another sector's behavior.

3.3.4 Scenario development

Elaborating future scenarios is a very important and delicate topic in developing any tool to simulate the effects of climate change on the environment and society implicitly. If climate scenarios make things easier, as quantitative quantifications and measurements of various indicators already exist such as rainfall, temperatures, emissions, etc., in the case of quantifying the socio-economic parameters, things become more complicated. Usually these scenarios are elaborated in the form of stories or trends of various economic and social factors that influence together with the climate scenarios the impact resulted due to current or future conditions. Most of the scenarios developed so far have the disadvantage that in most cases they cannot be easily reproduced if one wishes to reuse them, the conversion from qualitative to quantitative is not always possible and it is harder to maintain the consistency among the qualitative scenarios than the quantitative ones. CLIMSAVE has used the scenario development experience from previous projects in developing its own scenarios using a procedure to turn qualitative scenarios in quantitative values especially with the help of stakeholders, also designing a procedure to reproduce these scenarios in different or similar contexts.

3.3.5 Cost-effectiveness assessment of proposed adaptation solutions

Similar to the adaptation to climate change, where not even the solutions that should be applied are clear, in terms of their cost-effectiveness ratio, even less calculations have been done to confirm or deny the need to use them. The uncertainty of these calculations stems from the complexity of the existent and necessary adaptation measures, but also from the inter-sectorial repercussions that would arise. CLIMSAVE has analyzed existing approaches and developed a way of calculating an adaptive capacity based on social, economic and natural aspects, identifying the sensitive sectors and the links between them. This adaptation indicator has been incorporated into the integrated assessment platform, allowing a financial assessment for the application of adaptation solutions integrated within the platform.

3.3.6 Vulnerability assessment

The ability to assess vulnerability is very important as it allows the delimitation of regions, populations and ecosystems that are potentially at risk due to various changes in the natural or anthropic environment. The steps to be taken following the vulnerability assessment are to identify the underlying causes and to identify the measures to be implemented by the decision-makers. If past vulnerability assessment was done on the basis of data collection at a given time, CLIMSAVE is studying historical data and trying to identify the vulnerabilities that have occurred over time and between the different sectors that interact. A multidimensional approach is considered, taking into account a number of stress factors, sectors, actors and adaptation policies.

3.3.7 Uncertainty assessment

Within the integrated assessment platform, the occurrence of uncertainties is inherent due to its components: simulation of impacts, proposed adaptation methods and vulnerability assessment. Thus, sources that can induce uncertainties are multiple: the quantification of parameters, the uncertainty of models and the propagation of errors between them due to their chaining, but also the uncertainty of the data sets used. In the analysis of uncertainties, several methods and tools have been used over time. A novelty element introduced within CLIMSAVE is assessing the uncertainties that propagate between meta-models at sectorial and intra-sectorial level and finding patterns of propagation. Comparing the results obtained through IAP simulation with existing data and identifying an inconsistencies' pattern can give the direction of uncertainty research in terms of studying the results obtained by running the platform on future scenarios.

3.4 CLIMSAVE scenarios

Scenarios are generally conceived as ways to anticipate future trends and the direction of change in a wide range of domains starting from the natural one and ending with the anthropic one. In order to develop and actively integrate these scenarios into working tools, both CLIMSAVE and IMPRESSIONS have involved a series of knowledge from stakeholders, researchers and other actors from different sectors that have interacted with various factors whose influence is of interest. Both CLIMSAVE and IMPRESSIONS platforms provide users a range of future climatic and socio-economic scenarios which can be selected either individually or in various combinations.

3.4.1 Climate scenarios

Climate scenarios within CLIMSAVE are defined by customizing emission levels (A1b, A2, B1 or B2) - a classification provided by IPCC, choosing the sensitivity level (low, medium, high) and a global climate model (MPEH5, CSMK3, HadGEM, GFCM21 and IPCM4) [**10**]. These climate scenarios are characterized by temperature changes for 2050 between 1.1 and 4.9°C in winter and between 1.0 and 3.6°C in summer. The rainfall volume in winter within these climate scenarios vary with increases ranging from 1.1 to 12.5% and declines between 2.0 and 29.5% during summertime.

To be more specific the emission levels taken into consideration in CLIMSAVE were chosen from IPCC Special Report on Emission Scenarios (SRES) [**21**]. The scenarios developed in this report relate to future emissions and take into account an expanded range of factors that influence them such as economic, demographic or technological factors. The development of these scenarios is based on a thorough evaluation of the existing literature, six modeling possibilities and the experience and participation of over 50 people from 18 countries with diverse experience and professional background. *Figure 3.1* shows the scenarios developed in this report: four sets of scenarios A1, B1, A2 and B2 totalizing 40 individual scenarios. The A1 set is divided into 3 groups according to the energy-obtaining ways: A1FI (fossil fuel intensive), A1B (balanced) and A1T (non-fossil fuel intensive). Each of the four groups of scenarios takes into account different future directions of development by 2100. The directions proposed by them are often divergent taking into account a number of factors such as economic development, technological and demographic changes. The various trends considered in the development of these scenarios have not allowed the assignment of probabilities of occurrence for any of them.

A brief description of the scenarios proposed in this report and used in CLIMSAVE IAP is as follows:

- The scenarios in A1 group are aimed at a future world characterized by population growth in the first part of the century and a further decline, a fulminant economic and technological development. The three sets of scenarios comprised in this group are:
    - A1FI - scenarios where technological development relies on energy from fossil fuels
    - A1B - scenarios in which obtaining energy is not based solely on a specific source, but rather on a dispersed series of energy sources and on reducing losses in its production.
    - A1T - scenarios that rely on getting energy from sources that do not involve fossil fuels
- In the A2 groupings the focus is on regional development rather than a global one that results in a heterogeneous environment characterized by uneven population growth,

regional economic growth concentrated only on a category of population and a chaotic technological development.

- The scenarios in B1 group are characterized by a unitary global development with a population growth trend similar to the one in A1 scenario group. On the economic and technological side, they are following the same rapid development, taking into consideration resource and material reductions, as well as their rational use. These scenarios are more concerned about equity and sustainability in all areas.
- B2 scenario group is a gathering of all of the above scenarios with less aggressive tendencies. The tendency of technological and economic development is a growing one, but much less than in A1 and B1. The trend of economic, demographic and technological development is also regional, as it is in the case of A2 scenarios, with an emphasis on sustainability.

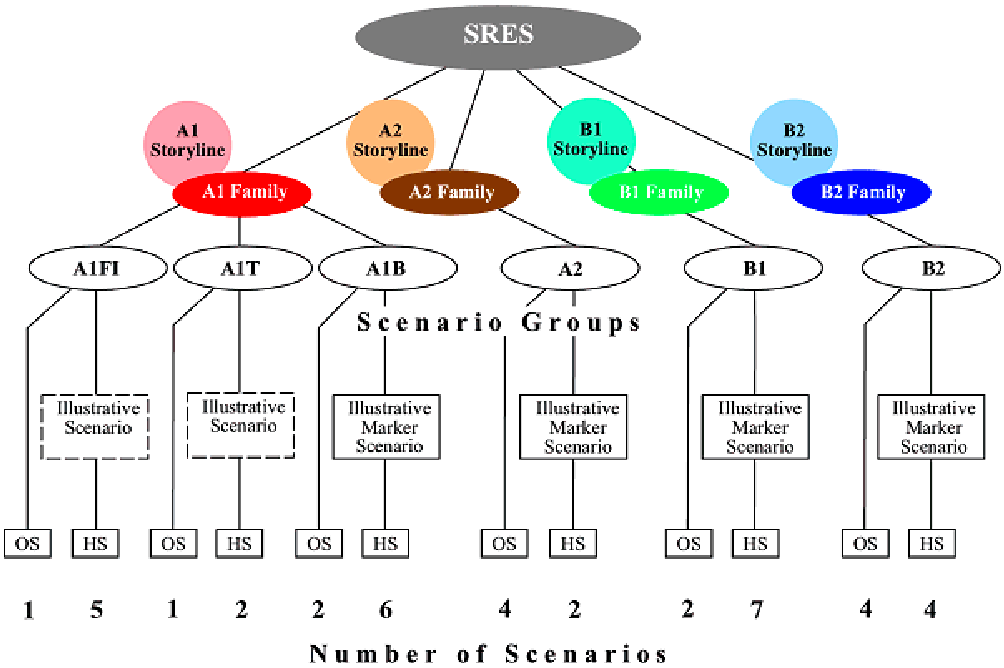


Figure 3.1 Emission level storylines and scenarios[5]

In terms of global climate models (GCMs) used in CLIMSAVE IAP for simulating future climate conditions, five of the sixteen existent developed by IPCC were selected. The method used to choose the five representative models was as follows:

- The best global climate model was chosen on the basis of a thorough analysis of existing models corroborated with the seasonal succession of precipitation and temperature data (Model chosen: MPEH5).
- A "central model" was chosen as being the closest to the centroid in terms of climatic values calculated on the basis of the 16 existing models (Model chosen: CSMK3).

[5] https://ipcc.ch/pdf/special-reports/spm/sres-en.pdf

- Three global climatic models were chosen. They are characterized by an increased uncertainty rate compared to the other existing models (Models chosen: HadGEM, GFCM21, IPCM4).

Emissions	**Climate Sensitivity**	**CSMK3**		**IPCM4**		**HadGEM**		**GFCM21**		**MPEH5**	
		W	S	W	S	W	S	W	S	W	S
		Average temperature change for 2050s (°C)									
B1	Low	1.7	1.1	1.3	1.3	1.1	1.3	1.2	1.1	1.2	1.0
B2	Medium	3.3	2.1	2.4	2.5	2.0	2.4	2.3	2.0	2.2	1.9
A1B	High	4.9	3.1	3.6	3.6	3.0	3.5	3.4	3.0	3.3	2.8
		Average precipitation change for 2050s (%)									
B1	Low	4.2	-2.0	2.5	-4.2	1.1	-9.6	3.6	-13.6	3.6	-7.8
B2	Medium	8.3	-3.4	4.9	-7.4	2.1	-16.8	7.2	-22.6	7.0	-13.6
A1B	High	12.5	-4.6	7.4	-10.3	3.3	-23.0	11.1	-29.5	10.6	-18.6

Table 3.1 European average changes for precipitation and temperature in winter (W) and summer (S)

Table 3.1 captures seasonal weather (summer/winter) climate change for rainfall and temperature for 2050. As one can easily observe, temperature increases vary between 1.1 and 4.9° Celsius during the winter and between 1 and 3.6° Celsius during the summer. From the precipitation point of view, the data shows increases from 1.1 to 12.5% during winter and decreases from 2 to 29.5% during summer.

3.4.2 Socio-economic scenarios

In terms of socio-economic scenarios, CLIMSAVE contains a series of four scenarios identified and quantified by stakeholders during a series of workshops conducted during the project [**16**]. The issues that have been considered were those that produce environmental, social and environmental changes. Based on these aspects, stakeholders summarized a list of uncertainties on the basis of which the four socio-economic scenarios were elaborated. *Figure 3.2* captures these uncertainties as two questions:

- Are the proposed solutions suitable for innovation effective or not?
- Should economic development be gradual or should it have the speed of a rollercoaster?

Figure 3.2 CLIMSAVE socio-economic scenarios

Scenarios take into consideration two development dimensions: "Economic Development" and "Solutions by Innovation". The scenarios developed are as follows:

1. We Are The World (WRW) - the most favorable scenario that combines a high level of innovation with a gradual economic development. In this scenario the attention is focused on the wellbeing rather than GDP. This approach should lead to a more equal distribution of wealth and the possible disappearance of inequality.
2. Icarus – the opposite of WRW, Icarus is characterized by static economics and policy decision-making on the short term.
3. Should I Stay or Should I Go (SoG) - scenario characterized by chained economic crisis that eventually leads to wide disparities between rich and poor, politic instability and conflicts.
4. Riders on the Storm (Riders) - similar to the SoG scenario, in which competent authorities succeed in coping with crisis situations, one of the recovery pathways is to invest in renewable energy and green technologies.

3.5 Platform design and implementation

This chapter presents the implementation of the CLIMSAVE IAP (Integrated Assessment Platform) [**55**], an interactive web platform developed within the framework of the FP7 EU funded CLIMSAVE research project (http://www.climsave.eu).

The developed platform is based on two frameworks: DPSIR (Driver-Pressure-State-Impact-Response) and MA (Millennium Ecosystem Assessment). The implementation of the two frameworks within CLIMSAVE is synthesized in *Figure 3.3*.

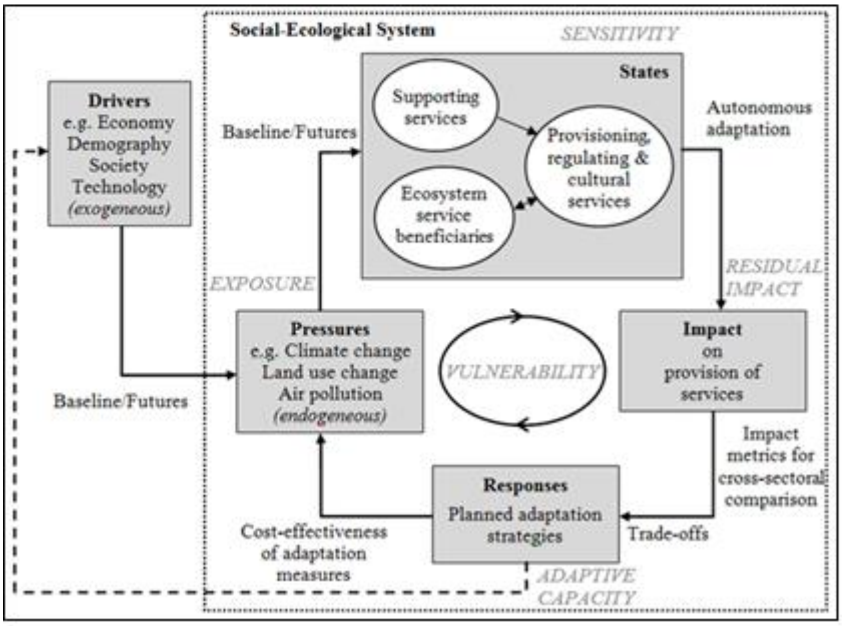


Figure 3.3 CLIMSAVE framework including DPSIR and MA frameworks[6]

DPSIR (*Figure 3.4*) was applied in the environment field since its appearance in 1993 [**9**]. It has been thought as a facilitator of the dialogue between different sectors that have to work together to solve environmental problems. It is also used by the European Environment Agency (*Figure 3.4* was taken from their official website). The advantage of this framework is that it simulates a system that includes both the environment and all its associated subsystems, as well as human interference. Its disadvantage is that as it is often used in simulating harmful human interventions in various sectors of the environment, it does not have a consistent view of the components within.

For CLIMSAVE, **drivers** are those external factors that influence environmental changes, such as socio-economic changes, be them past, present or future. **Pressures** are the internal factors that most often play a role in quantifying the external factors detailed above. These pressures are usually easy to quantify such as rainfall, temperature, population, etc. The influence of these pressures is reflected in the **states** component of the framework as a response to the system's sensitivity to internal factors. In this case **states** are defined by a series of existing sectorial meta-models. The **impact** side reflects how meta-model factors within **states** have managed to adapt to the disruptive internal factors within the **pressures** component, measuring their positive or negative impact. **Responses** refer to adaptation methods organized and planned in such a way to minimize the potential negative impact or maximize the benefits resulting from the application of **pressures**. Often, these measures are political but not only, for example: restricting water consumption or limiting urban development.

[6] http://www.climsave.eu

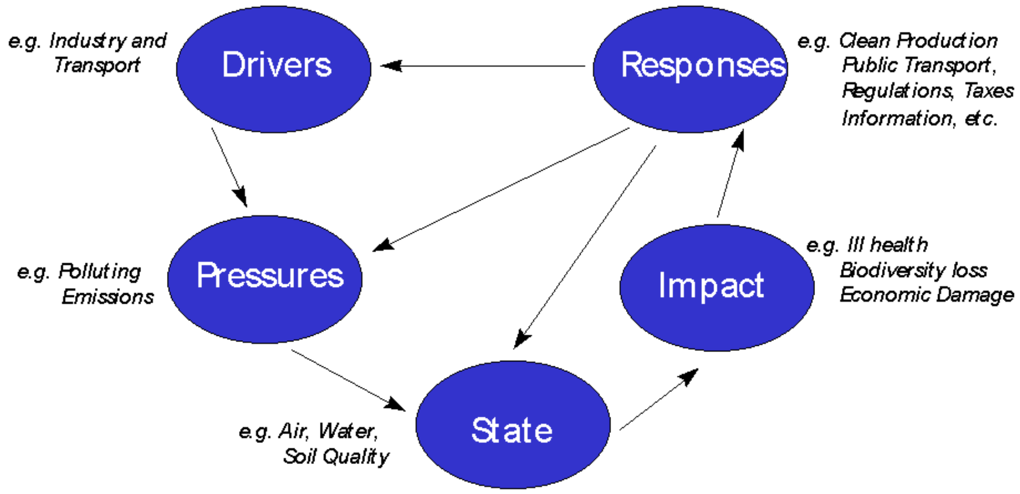


Figure 3.4 DPSIR Framework European Environment Agency[7]

The DPSIR Framework integrates with the MA framework that describes links between humans, ecosystems (cultural, provisioning and regulatory services) and direct and indirect change factors. Ecosystem services are those services offered to humans by nature and are spread across all the components of the environment: forests, water, natural and urban ecosystems. With such extensive coverage of the environmental sectors, this framework has been encapsulated within the **states** component of DPSIR being a good source of data and information for the meta-models included in this component.

In *Figure 3.3*, DPSIR indicators are represented as rectangles and the arrows between them present the order in which they are linked in the process. The internal factors are separated from the outside ones by being framed within a dotted boundary line. As mentioned earlier, external indicators are the drivers that most often represent the given conditions and on which one cannot intervene. *Figure 3.3* depicts, in other words, the methodology to identify impacts and vulnerabilities of climate change in a wide range of sectors driven by a series of **drivers** and **pressures**, thus leading to understanding the problems and identifying potential adaptation measures.

In order to effectively develop the platform, it was necessary to choose the technology to be used for implementation, as well as the way to store the data to be used within the platform. Also, another important matter to be established was the way the platform is visually available to users, in other words the graphic interface design. This has been developed with the help of the consortium members and stakeholders and has evolved throughout the project to the final version that is still being used.

[7] https://www.eea.europa.eu/publications/92-9167-059-6-sum/page002.html

3.5.1 Client-server architecture

The CLIMSAVE IAP has a client-server architecture, this approach allowing remote and secure access to the necessary information. Beyond the benefit of accessibility, the scalability and the possibility of upgrading the platform are two other advantages of this architecture. Therefore, any necessary change is made only on the server side and will be visible to any user who accesses the platform.

The CLIMSAVE IAP architecture depicted in *Figure 3.5* consists of two major components: one found on the Server side (Running Module) and the other one on the Client side (Client Interface Module).

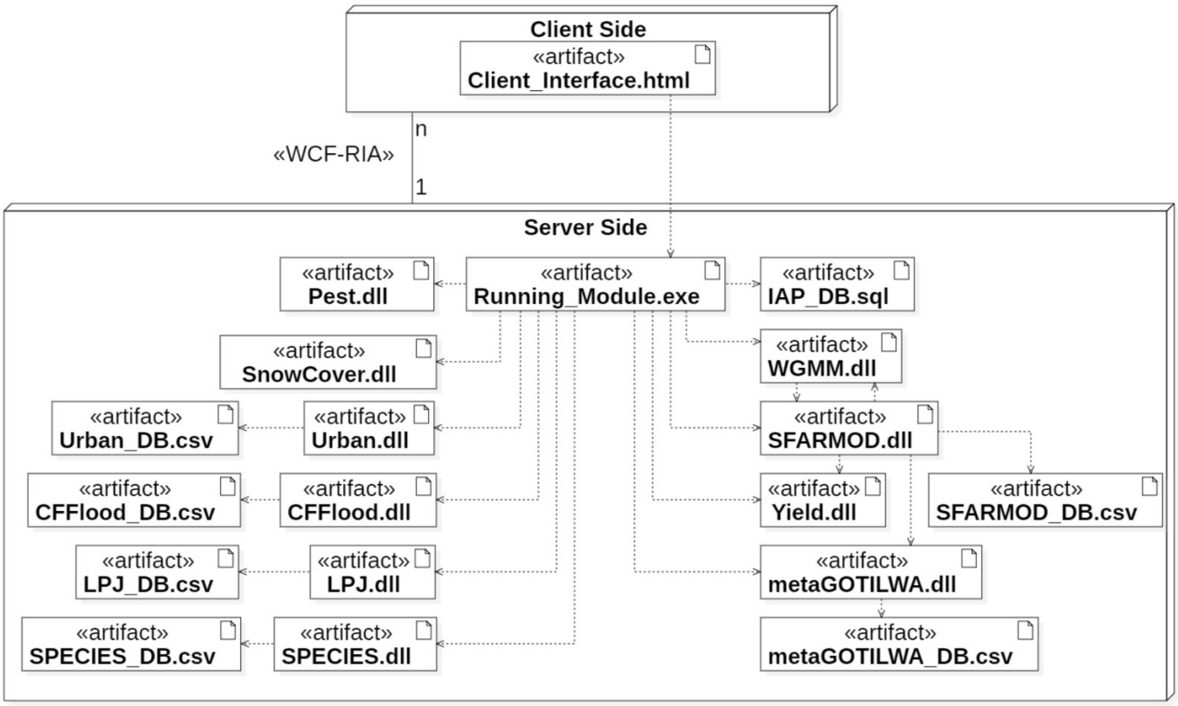


Figure 3.5 CLIMSAVE architecture (UML deployment diagram)

The graphical user interface on the **Client side** was developed using Microsoft Silverlight technology, the communication between client and server being made through WCF-RIA (Windows Communication Foundation - Rich Internet Application) protocol. This framework was chosen for its high degree of interactivity, its encapsulation of a wide range of multimedia and web services, as well as many graphic facilities. Its compatibility with Windows and Mac OS operating systems was also a reason for which it was chosen. Among the advantages of using this technology in CLIMSAVE IAP are:

- client-server synchronous and asynchronous communication for meta-models results display
- facility of using geospatial maps for displaying results
- ease and speed of client-server communication

The communication between the user (the graphical interface) and the server is done through the **Client Interface Module** that collects the information from the graphical interface (input parameters or other selections made by the user) and sends them to the server. The results obtained are also received through the Client Interface Module, which from time to time sends requests to the server to determine if the outputs are ready. They are collected by the same component on the **Client** side and displayed on the map provided in the input/output interface.

The **Server** part contains the components dealing with the computational part of the platform:

- CLIMSAVE **IAP** database
- Sectorial meta-model components and their specific databases
- **Running Module** component

CLIMSAVE IAP database, containing climate, physical and socio-economic information, is located on the server, as there is no need of transferring data on the user's host computer, thus minimizing runtime. The server also contains 10 **meta-model components** that correspond to the sectors that are referred and integrated within CLIMSAVE. The meta-model components were developed in different programming languages such as Microsoft C#, VB, C++, and also Delphi, each meta-model resulting in a DLL (Dynamic-Link Library). This approach allowed each meta-model component to be developed by specialists in the field, in contrast to a non-modular approach which would have meant that only one person would have had control of the whole information flow.

The main component located on the server side is the **Running Module** that performs the following operations:

- collects information from the client module
- analyzes the data and receives requests
- interrogates the CLIMSAVE IAP database to obtain the input data required for meta-models
- populates the meta-models input variables with the data received from the Client, data from the IAP database or from the execution of other meta-models
- runs the meta-models in a certain order, established a priori
- collects the results obtained from each meta-model separately
- sends the results to the Client Interface Module

The technical specifications of the **Server** on which CLIMSAVE IAP is running are as follows:

- Operating system: Windows Server Standard 2008 (64 bits)
- CPU: Intel(R) Xeon(R) CPU X3450 @ 2.67GHz 4 Cores
- RAM: 8GB (DDR3)

3.5.2 Designing CLIMSAVE IAP Graphical User Interface

3.5.2.1 GUI requirements

CLIMSAVE envisaged bidirectional connection regarding the communication of project results to users and stakeholders. If most of the research projects report a series of results based on predefined scenarios or situations, CLIMSAVE brought in the idea that the process of transmitting knowledge and results displayed in the integrated assessment platform should be a learning one in which users can create, test and eventually validate their own scenarios [**20**].

The main requirements for the CLIMSAVE IAP GUI were derived with the help of project participants who have great experience in developing graphical interfaces for platforms and software tools addressing the problem of simulating the impacts of climatic effects. These are:

- The platform should allow easy and interactive use of all the features provided by the platform: impact and vulnerability assessment of climate change, investigation of adaptation options and the cost introduced by them.
- The platform must provide the user with the possibility to select the desired scenarios and customize them according to their needs with numerical values and less with qualitative ones.
- In order to conserve consistency, the change of input values for meta-models should be allowed only between certain intervals. The GUI must be an intuitive interface one, giving the user information about the variables that he can modify and their fluctuation range.
- The input indicators that can be modified within the platform should be structured according to the sectors they influence. Thus, depending on the user's wishes, he can modify those indicators he is interested in or for which he has competence without having to review all parameters, which would lead to a long process of preparation for running the platform.
- In terms of running speed: running the platform should not take a long time (up to five minutes) so that user’s attention is not lost. For this purpose, a meta-modeling approach was considered appropriate to simulate the existent procedures in different sectors. Also, in order to keep the user's interest, the results obtained from the run of the meta-models are displayed as soon as they are obtained. So, it is not necessary to have the run of all meta-models completed to display the results obtained by each meta-model.

3.5.2.2 GUI implementation

In order to develop CLIMSAVE IAP GUI to pursue the above requirements, a number of functionalities for users to benefit from were selected. Therefore, the user is able to:

- choose the timeslice for which he wants to simulate the impact of climate change: Baseline (1990), 2020 or 2050

- select scenarios:
  - Emissions: A1, A2, B1, B2
  - Climate:
    - Climate model (GCM): CSMK3, HadGEM, GFCM21, IPCM4, MPEH5
    - Climate sensitivity: low, medium, high
  - Socio-economic: We are the world, Should I stay or I should go, Riders on the storm, Icarus
- run the platform both in an integrated manner or standalone which means running each meta-model separately
- visualize the results in a graphical way plotted on a GIS map and divided into impact indicators or ecosystems indicators
- export results to files with formats that allows them to be further analyzed

The GUI is structured in four different sections accessible in different screens [**55**]:

- **Impact section** - is the part where the user can see plotted on the map the impact of a scenario of climate change for each sector included in the platform - *Figure 3.7*
- **Adaptation section** - allows the modification of critical input variables for the selected scenario within the Impact section in order to reduce the negative impacts of climate change - *Figure 3.13*
- **Vulnerability section** – here the user can identify vulnerable areas in Europe according to the chosen scenario, but can also investigate the extent to which the adaptation options were effective or not - *Figure 3.16*
- **Cost-Effectiveness section** - estimates the relative cost of adaptation measures taken to reduce the impacts of climate change - *Figure 3.17*

Figure 3.6 illustrates the evolution of the CLIMSAVE IAP Impact Screen from its first version to the final one. In the process of developing the interface, the opinions expressed by the project participants and stakeholders were taken into consideration.

Running the meta-models in the Impact section is required to access any of the other 3 sections. The **Vulnerability** section can be accessed both after running the **Impact** section and after running **Adaptation** to see to what extent adaptation measures were suited to reduce vulnerabilities. The **Cost-effectiveness** section can only be accessed after running the **Adaptation** section for which the platform makes an assessment of the cost of adaptation measures.

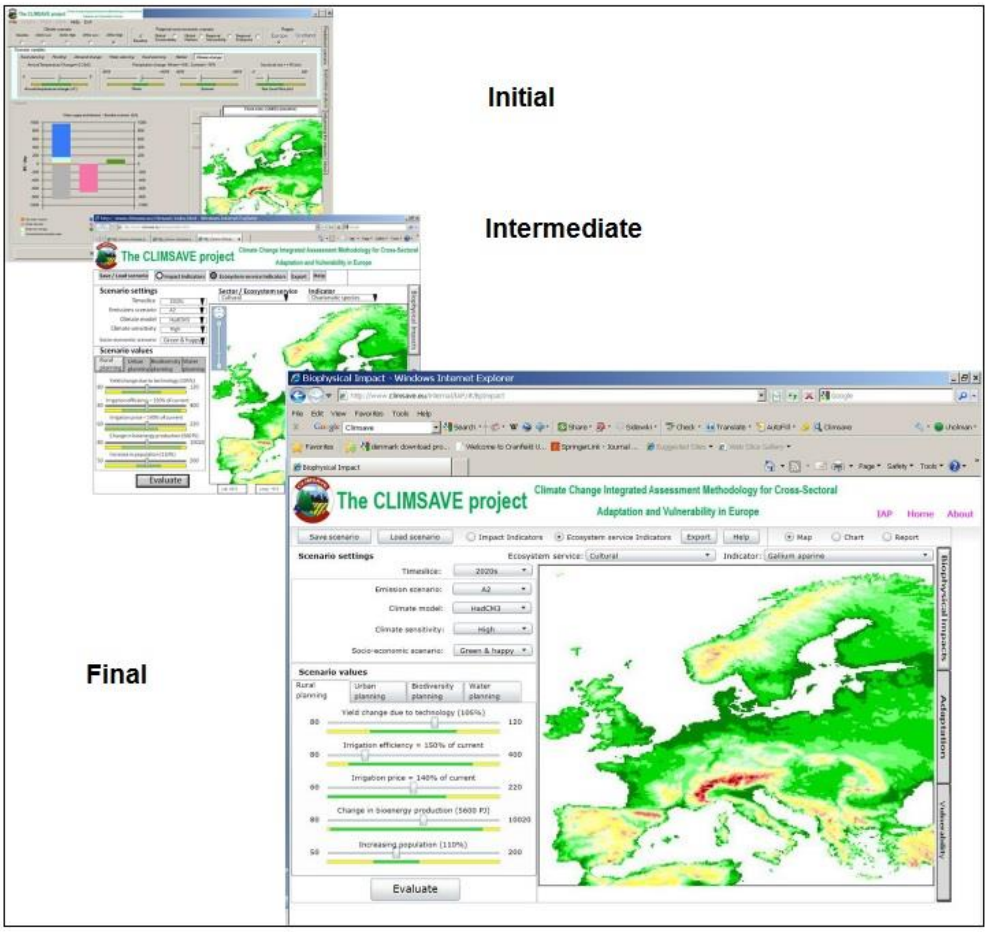


Figure 3.6 CLIMSAVE IAP - Impact Screen progress

3.5.2.3 Impact section

As mentioned above, in this section the user can visualize the impact of various climate and socio-economic scenarios for the sectors integrated in the platform.

Figure 3.7 shows the CLIMSAVE IAP opening page, namely Impact. To visualize the impact simulated by the platform, the user must execute the following steps that are also synthesized in *Figure 3.7*:

1. Choose the timeslice for which he wants to start the simulation: Baseline, 2020 or 2050 (default: Baseline)
2. A. If baseline is selected the user should manually set the climatic indicators: change in annual temperature (default: 0° Celsius), change in summer and winter precipitation (default: 0 mm), CO_2 concentration (default: 350 ppm) and sea level rise (default: 0 m). If the user does not change any of these indicators they remain the same as they were set according to the Baseline climatic scenario.

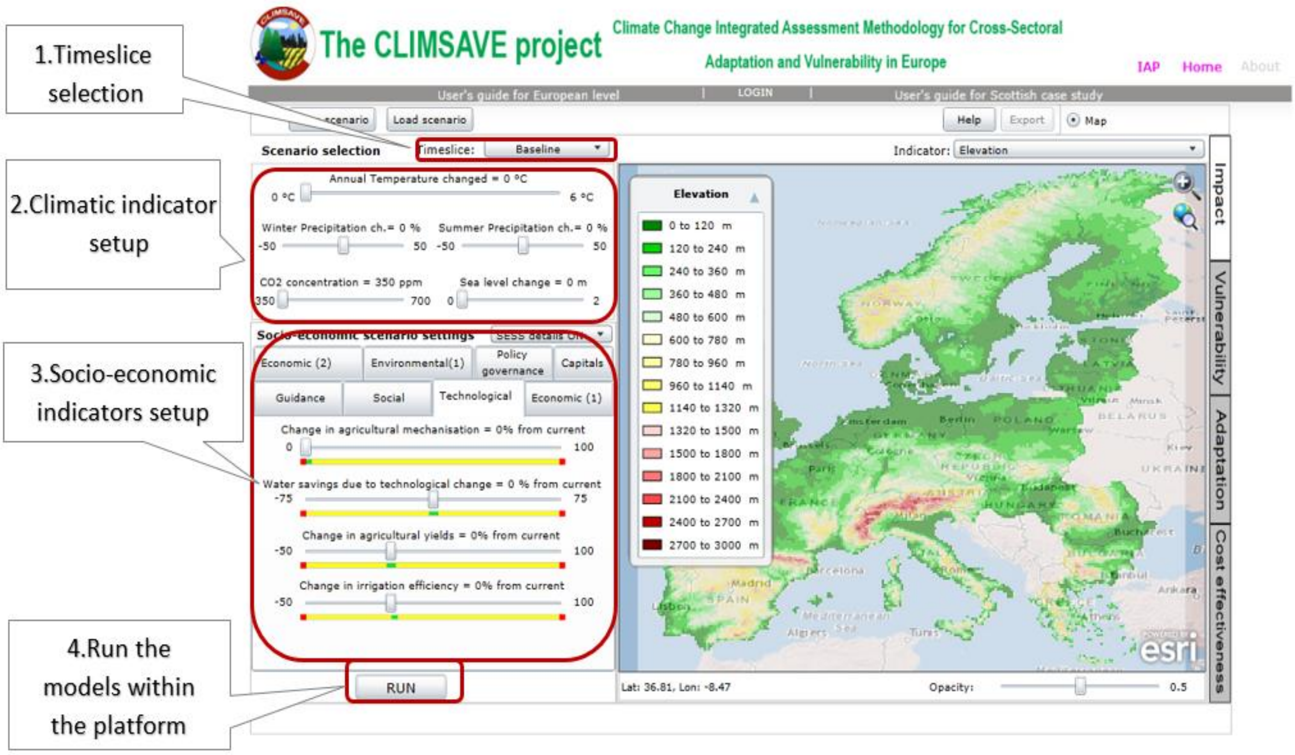


Figure 3.7 CLIMSAVE IAP – Impact section (Baseline timeslice)

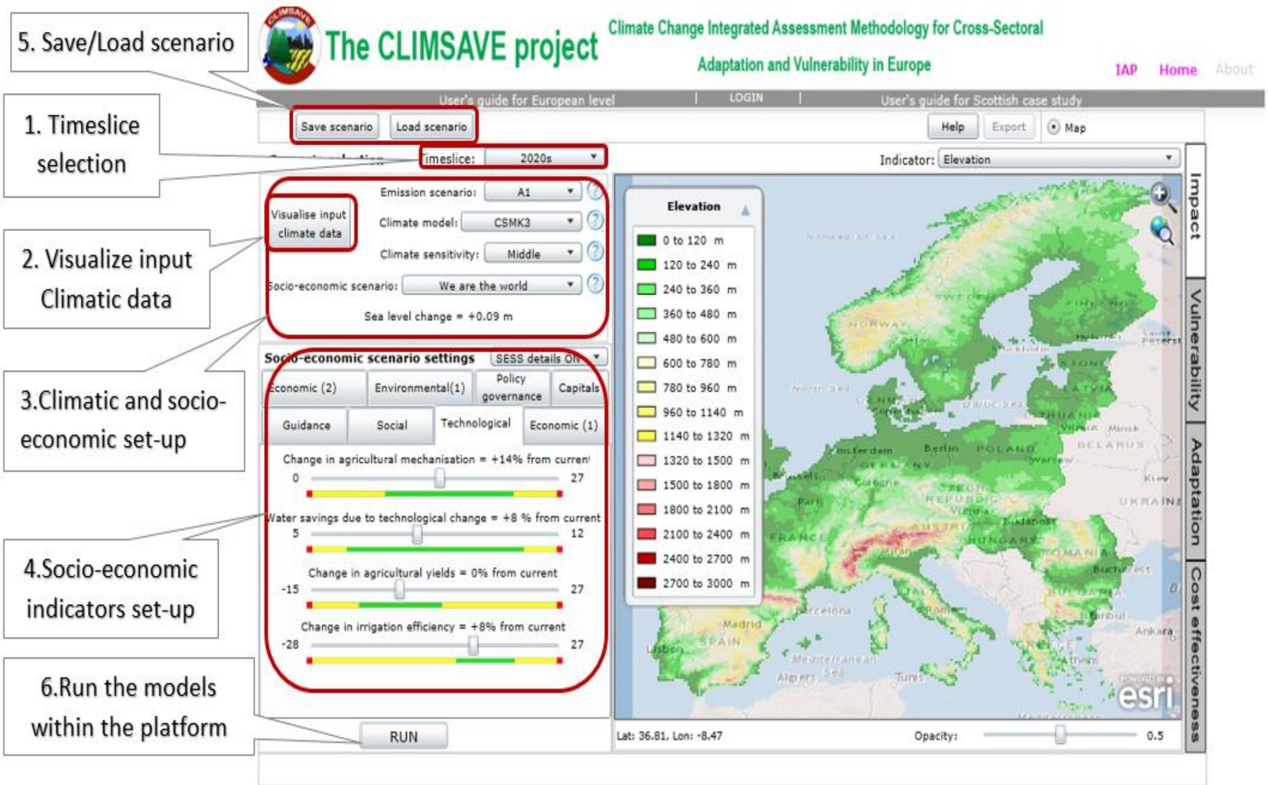


Figure 3.8 CLIMSAVE IAP – Impact section (2020 timeslice)

B. If 2020 or 2050 is selected the user can choose (*Figure 3.8*):
- Emission scenario: A1, A2, B1 or B2 (default: A1)
- Climate model (GCM): HadGEM, GFCM21, IPCM4, CSMK3 or MPEH5 (default: CSMK3)
- Climate sensitivity: Low, Middle, High (default: Middle). Using the "Visualize input climate data" button a new page opens where climate data (minimum / average / maximum temperatures, precipitation and radiation be them annual or seasonal) can be viewed and with which the platform feeds meta-models (*Figure 3.9*)
- Socio-economic scenario: Baseline, We are the world, Icarus, Should I stay or Should I go, Riders on the storm (default: We are the world)

3. Change the socio-economic input parameters, most of them depicted as sliders. Since the modification of these indicators may be non-intuitive in the sense that their modification may produce unexpected effects, a table of guidelines has been developed by CLIMSAVE consortium in which the user can get an idea of what the input variables can do and modify them accordingly (Annex 1). Sliders have two components as shown in *Figure 3.7*:
   - a numerical component in which the numeric value of the indicator is specified
   - a graphic component through which the user can change the value of the indicator. The colors available under each slider have the following meanings:
     - The green color represents the interval in which the indicator values are considered credible and safe, accordingly with the socio-economic scenario selected.
     - The yellow color signifies the intervals in which the indicator values have not been quantified as credible for the correspondent socio-economic scenario.
     - The red color includes the area where the indicator is not allowed to take values.
4. If the user did not run a predefined scenario made available by the platform, he could customize his own future scenario and save it for a later run.
5. Select the species for which the user wishes to track the impact of climate change. The user has to choose one group of species from both available sections (*Figure 3.10*) and press the "OK" button to start the actual run.
6. Observe the order of meta-models run at the bottom of the interface (*Figure 3.11*). As soon as a module finishes running, the results are displayed to the user.
7. View results (*Figure 3.11*):
   - The results that can be investigated are divided into sectoral variables (Urban, Coping Capacity, Tourism, Water, Flood, Pests, Habitat/Land Cover, Agriculture, Forestry, Biodiversity) or ecosystem variables (cultural, regulating and provisioning services). The sectorial ones are in turn structured according to the sectors for which they are representative. The indicators from each category are available in Annex 2.

- The platform allows the results to be viewed either in absolute values or relative to baseline.
- The platform provides the facility to display aggregate indicators across Europe.
- In order to store the results, the platform allows the export of all output indicators to a CSV file.
- If the colors with which results are represented or the intervals in which they are mapped are not suited to user requirements, they can be changed by pressing the "Set Legend" button (*Figure 3.12*) for which the following features are available:
  - The minimum and maximum values of the indicator
  - Adding or removing classes in which the results are distributed
  - Changing the precision of class intervals
  - Modifying both colors and limits of a class
  - Changing the colors of all classes according to a chosen color scheme (e.g.: Red monochromatic)
  - Automatically change the intervals in which the results are divided according to a chosen classification method (Manual, Equal interval, Natural breaks, Logarithmic scale, Quantile)
  - Saving the personalized legend that can be used later
- The map on which the results are plotted has Zoom in/out and opacity facilities.
- Moving the cursor on the map will display at the bottom of the map the geographical coordinates of the cursor and the output indicator value for those coordinates.

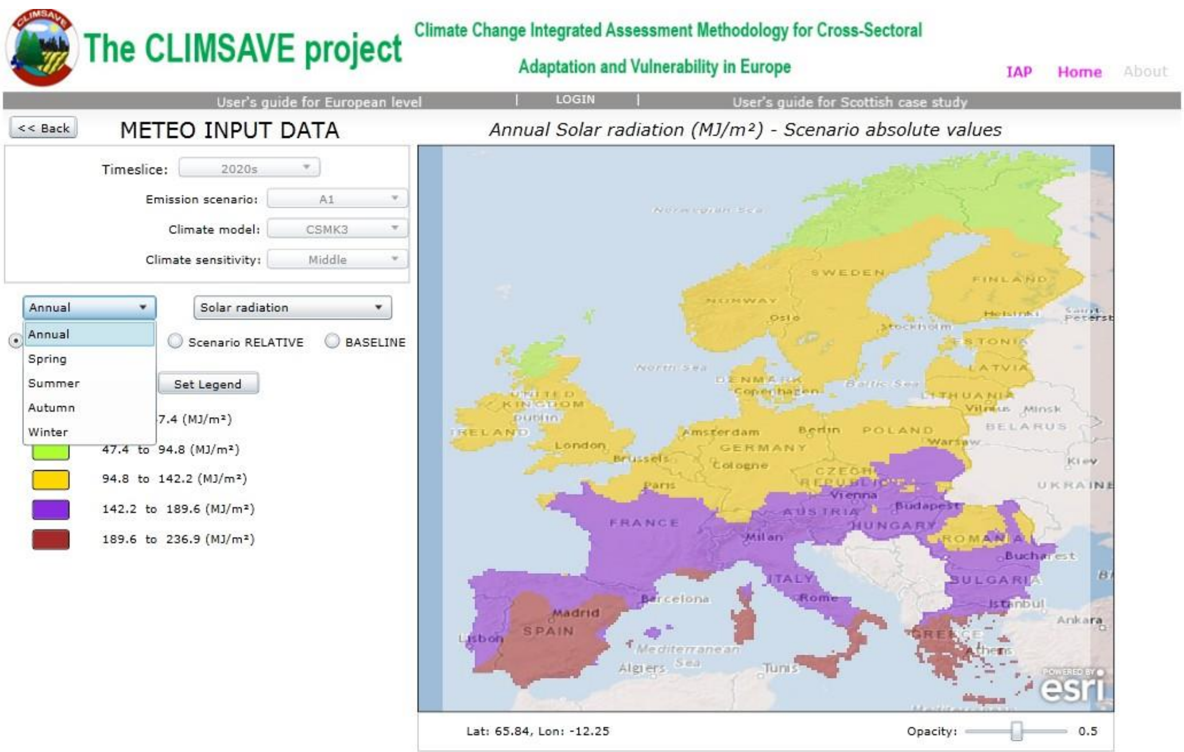


Figure 3.9 CLIMSAVE IAP – "Visualize input climate data" feature

Figure 3.10 CLIMSAVE IAP – “Species screen” in Impact section

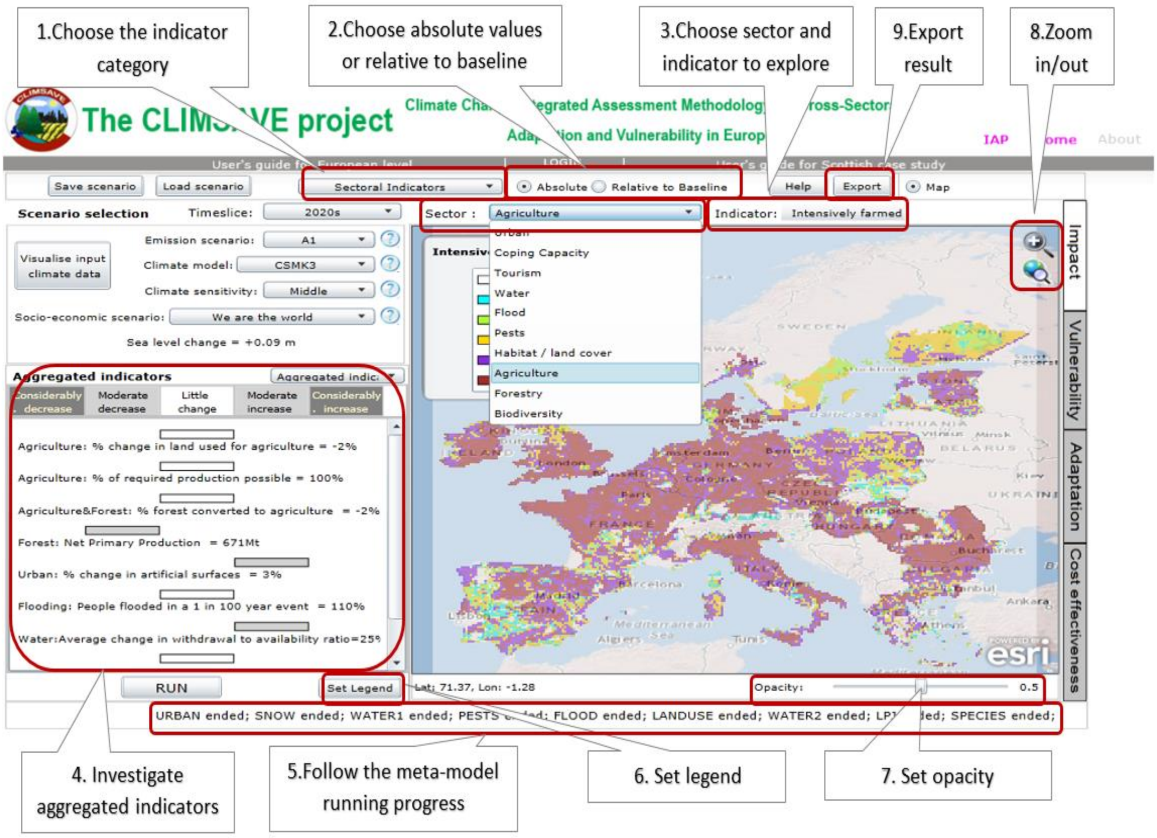


Figure 3.11 CLIMSAVE IAP – Output examination

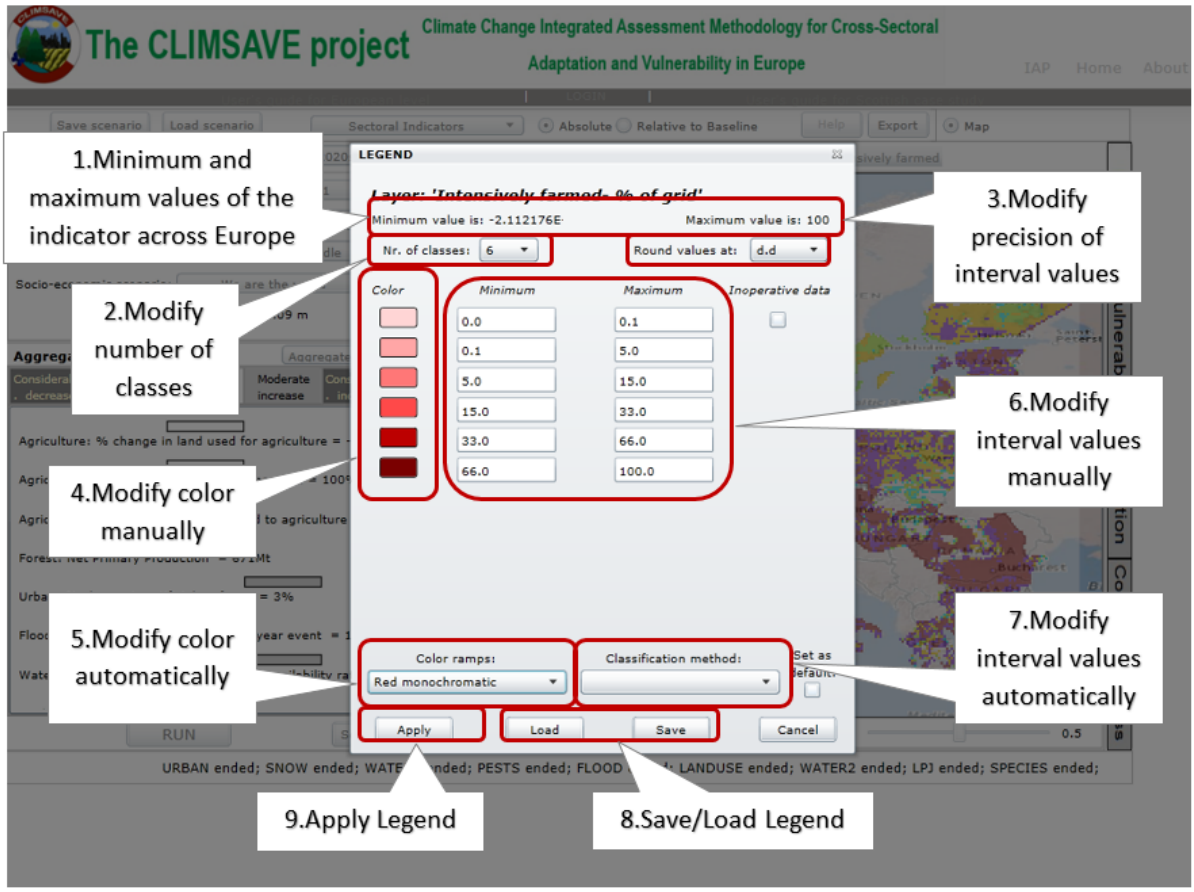


Figure 3.12 CLIMSAVE IAP – "Set Legend" options

3.5.2.4 Adaptation section

To explore to what extent adaptation can reduce climate change impacts, CLIMSAVE IAP provides the Adaptation screen where users can modify a series of input indicators (mostly the same input socio-economic indicators from the Impact section) in order to temper the damage that can occur.

If the user identifies in the Impact section one or more output indicators with values that exceed the acceptable limits for that indicator, he can try various alternatives in the Adaptation screen to try to reduce the impact accordingly (*Figure 3.13*):

- Identify the input indicators that should be modified to reduce the impact according to the indications in Annex 1. Note that not all socio-economic indicators in the Impact section are also available in the Adaptation screen (e.g.: Population change)
- Modify the input indicator/s identified at point 1. Slider variables should be modified taking into account that the new value should remain in the green-colored range, considered to be credible in the context of the scenario selected in the Impact section.
- Rerun the platform.

- View the results obtained by comparing them either with the baseline situation ("Relative to Baseline") or with the Impact one ("Relative to Impact") for which the impact was identified. These two comparisons can help the user realize whether the adaptation measures chosen have had an effect or if he should try again.

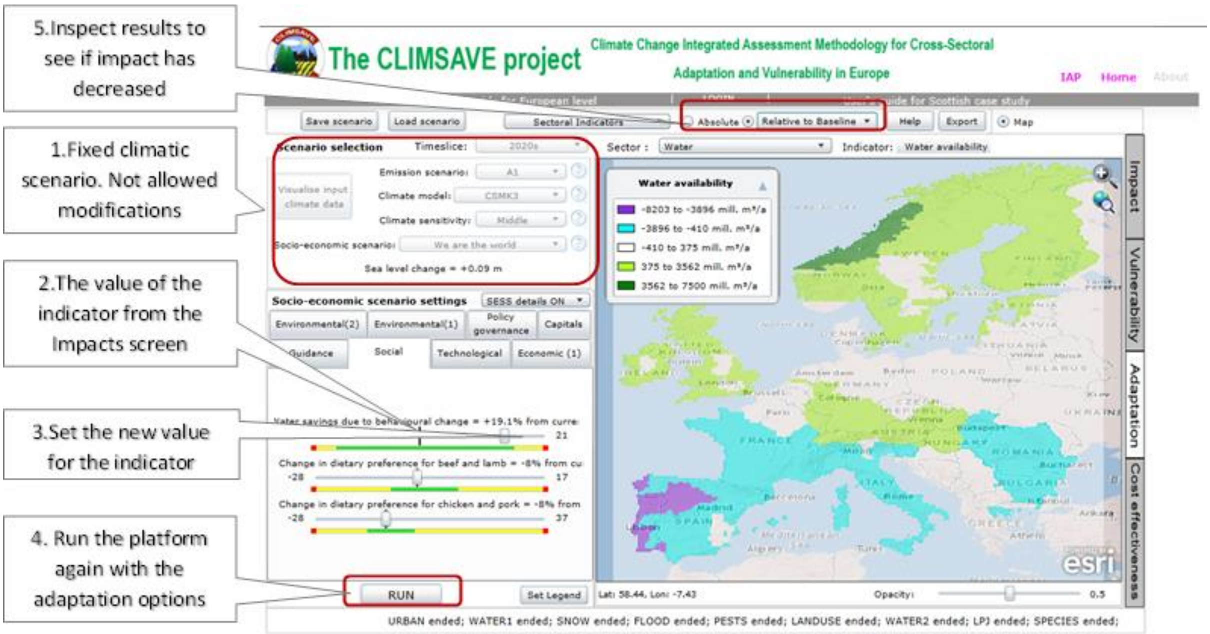


Figure 3.13 CLIMSAVE IAP – Adaptation section

- If a new adaptation strategy is to be attempted, the user must consider:
  - a larger increase in the input indicators already modified in the first adaptation attempt that should continue to remain within the credible (green) range of the scenario or exceed it and go into the yellow range only if this growth is a feasible one.
  - increase capital available in the platform (*Figure 3.14*). This increase in capital, changes the credible ranges of the sliders which are influenced by them. Capital growth should be proposed only to the extent to which this increase is possible and feasible. The types of capital included in CLIMSAVE and a brief explanation of their significance in this context are:
    - Human capital - includes the health, knowledge, skills and motivation of an ecosystem service beneficiary, as well as their individual emotional and spiritual capacities. It characterizes the abilities that lie within an individual member of society. It broadly covers areas of education, job experience, skills and health Human capital can be used for adaptation by, for example, using skills to provide early warning or providing training.
    - Social capital - consists of the structures, institutions, networks and relationships that enable individuals to maintain and develop their human capital in partnership with others, and to be more productive

when working together and not in isolation. It includes families, communities, businesses, trade unions, voluntary organizations, legal/political systems and educational and health institutions. Social capital can be used for adaptation by, for example, setting up voluntary organizations for emergency help.

- Financial capital - reflects the productive power of the other forms of capital and enables them to be owned and traded. However, unlike other types, it has no or only little intrinsic value, and reflects the ability of a nation to claim resources by calling in debts from overseas.
- Manufactured capital - consists of material goods, tools, machines, buildings and other forms of infrastructure that contribute to the production process but do not become embodied in its output. Manufactured capital can be created for adaptation by building dams, water pipelines, sea-walls, hospitals, roads, etc.

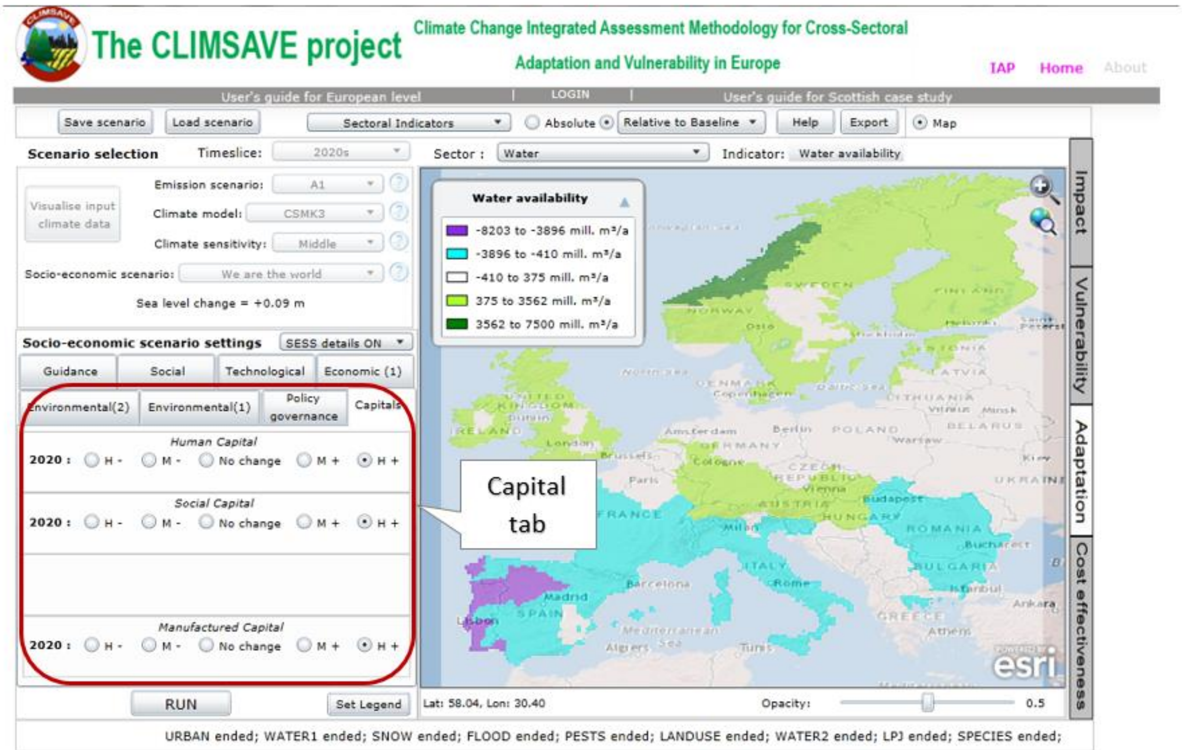


Figure 3.14 CLIMSAVE IAP – Capitals in Adaptation section

The credible (green) ranges in which the socio-economic indicator values can be changed are calculated according to:

- Adaptive capacity which is the ability of the system to adapt to climate change based on capitals that can limit these intervals, depending on the chosen socio-economic scenario.

- The importance of the adaptation option which is the likely importance to get a favorable response within the selected socio-economic scenario.

Even if the user discovers an adaptation option that can cope with the harmful impact determined within the Impact section, it should be investigated to what extent the adaptation measures adopted within the platform can be implemented in real life.

3.5.2.5 Vulnerability section

Investigating vulnerability at European level involves identifying regions where the system cannot cope with the negative effects of climate change. The capacity of the system to cope with climate change is called coping capacity in CLIMSAVE IAP.

Since the user can study the Vulnerability section both after running the Impact section and after running the Adaptation section, in terms of vulnerability, there are two types of impact:

- Potential impact – resulted from running the platform from the Impact screen
- Residual impact - resulted from applying the adaptation to the initial impact

Next, within this section, by using the general notion of impact, both the above detailed types are referred.

Each cell unit within Europe is characterized by one of the four types of vulnerabilities existing in CLIMSAVE IAP (*Figure 3.15*):

- Not vulnerable with insignificant impact – low impact causing no vulnerability
- Not vulnerable with sufficient coping capacity – the available coping capacity is sufficient to cope with the induced impact
- Vulnerable with insufficient coping capacity – the available coping capacity is not sufficient to cope with the induced impact
- Highly vulnerable – the impact is so great that it is impossible to cope with it

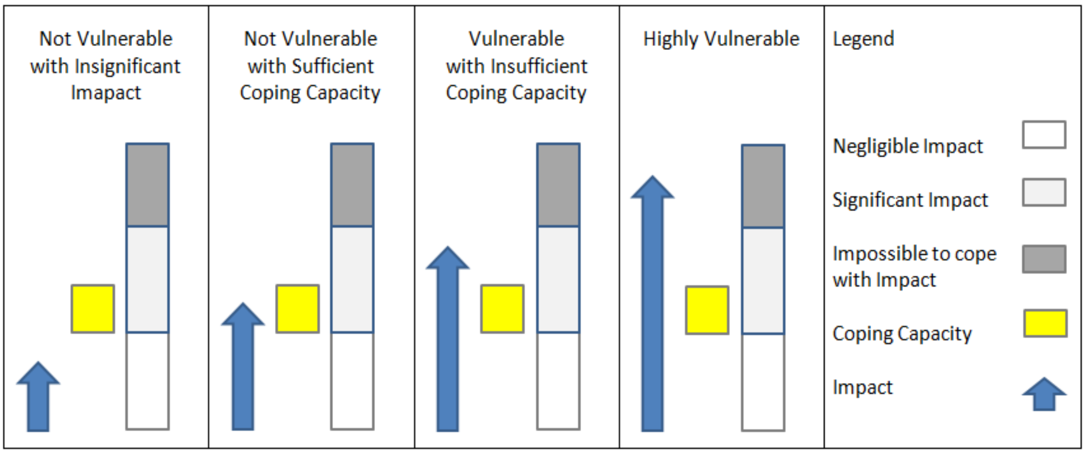


Figure 3.15 CLIMSAVE IAP – Vulnerability categories

In other words, vulnerable regions are those regions where coping capacity is insufficient. The representation of Europe's vulnerable regions on the map is available for six predefined parameters, each of them being a representative output indicator for a particular sector (*Table 3.2*).

Service type	Vulnerability Indicator	Scale	Description
Provisioning	Food provision	Grid cell	Food per capita reflects the basic human need for provision of nutrition (Kcal/day).
Provisioning	Water exploitation index	River basin	The ratio of annual withdrawals to annual availability, reflecting the basic human need for the provision of fresh water.
Regulating	Flood index	Grid cell	People flooded in an event that happens once in 100 years reflects the direct impact of flooding on human well-being.
Supporting	Biodiversity index	Grid cell	Reflects the role of biodiversity in the provision of ecosystem services and the consequences of biodiversity loss for human well-being.
Cultural	Intensity index	Grid cell	Reflects the negative consequences of land use intensification in terms of broader environmental quality as well as cultural, spiritual and aesthetics impacts on human well-being.
Multiple ecosystem services	Land use diversity index	Grid cell	Reflects the importance of multi-functional landscapes in support of human well-being by providing a broad cross-section of ecosystem services.

Table 3.2 Vulnerability Indicators

Figure 3.16 depicts the features provided by the Vulnerability screen:

- Inspect the impact on the selected indicator.
- Inspect coping capacity at all indicator levels.

- By selecting a single vulnerability indicator or a series of indicators the platform can indicate the regions that are not vulnerable to any indicator but also areas that are vulnerable to multiple indicators.

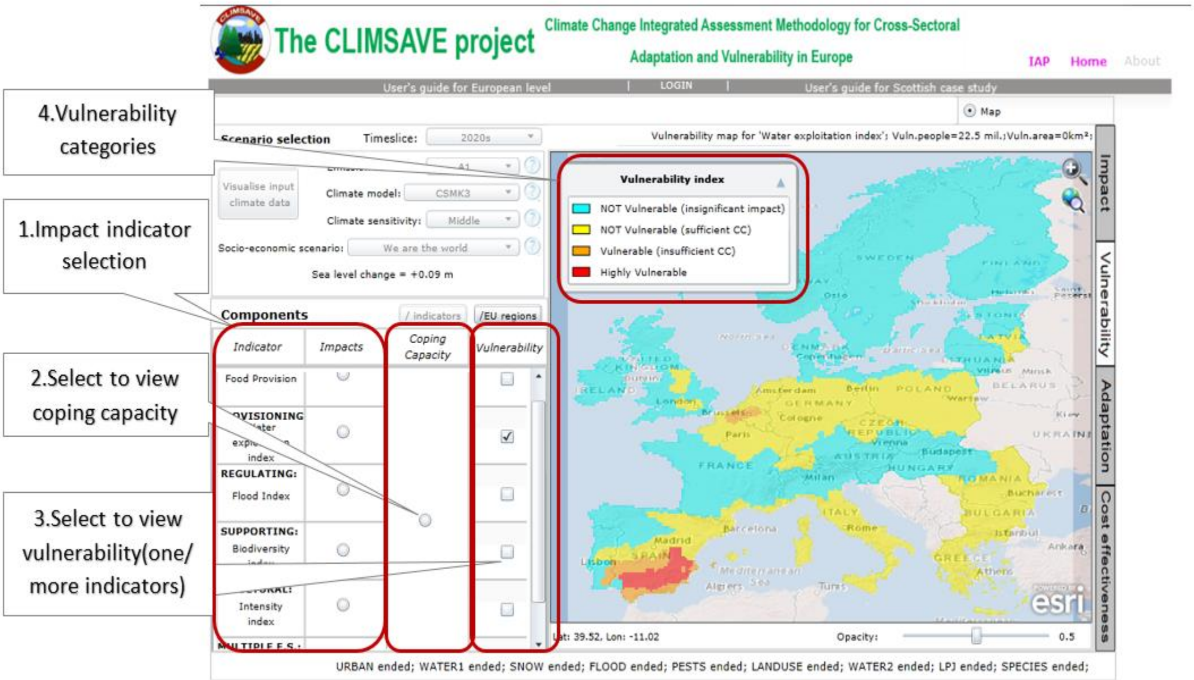


Figure 3.16 CLIMSAVE IAP – Vulnerability section

3.5.2.6 Cost-effectiveness section

The Cost-effectiveness screen is only available after running the platform along with the adaptation options and provides the user with:

- Assessing the cost-effectiveness of the adaptation measures that are to be implemented.
- Assessing the potential of a measure of adaptation in relation to the entire adaptation vision that was thought in the Adaptation section.
- The capital limiting the implementation and obtaining the best results from running the adaptation measure.
- The inter-sectorial (positive/negative) effects that adaptation measures may have on some sectors.

This section provides for each modified input indicator on the Adaptation screen a series of "hard" and "soft" adaptation measures that can be implemented. The above information is available for each such adaptation measure (*Figure 3.17*).

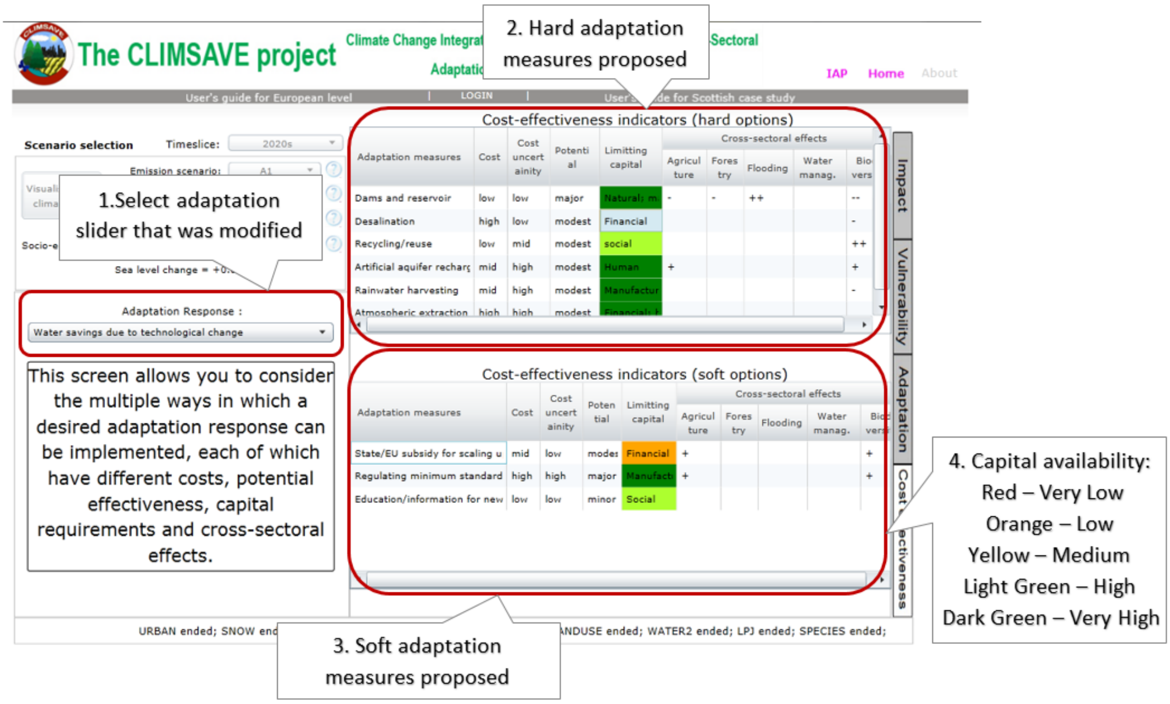


Figure 3.17 CLIMSAVE IAP – Cost-effectiveness section

The qualitative costs estimated by CLIMSAVE IAP are informative. The uncertainty of their calculation is highly given by various factors that may influence the implementation of adaptation measures.

The CLIMSAVE IAP has as main features fast response times, ease of use and wide availability and is intended to simulate a large scale of impact indicators from a series of natural, social and economic key sectors among which: urban, water, agriculture, forests, coasts, land use and biodiversity. These simulations offer people the possibility to understand and be aware of the disastrous effects that mankind actions may have on the natural environment, climate factors and ecosystem services.

3.5.3 Meta-model components

In view of easy integration of the sectorial meta-models within the platform, these were thought to be independent software components in the idea of being able to be replaced at any time with improved versions whenever this is needed.

The meta-modeling technique was chosen to provide the platform with the necessary computing speed. Meta-models are in fact simplified versions of existing sectorial models, most of them running as desktop software tools. The advantage of using existing models is that they have already been tested and produce credible and up-to-date results. However, being very complex they could not be integrated the way they are into the platform and were simplified.

Meta-models simulate the evolution of various indicators in a number of sectors across the environment between which interactions exist. These interactions are realized without any human intervention, do not have any specific purpose and are transposed into the software platform by fixed links between meta-models, more precisely some output indicators from a meta-model are passed by the platform as input indicators to another or even other meta-models. In order to identify the links between meta-models and the way they interconnect, it was necessary to develop a specification for each meta-model to help them communicate without taking into account the algorithm implemented in each of them. Because this meta-model specification is complex, a series of stages have been followed which are detailed in the following subchapters.

3.5.3.1 Data resolution

For a good definition of meta-model specifications, the resolution at which data is transmitted must be established at first. The resolution at which CLIMSAVE IAP operates is 10'x10' (~16kmx16km) and corresponds to the Climatic Research Unit's baseline 1961-1990 climatology [**26**]. This resolution includes 23181 European terrestrial cells over which the results obtained in the platform are mapped and displayed to the user in an interactive GIS map. Based on an analysis, it was established that the resolution at which the data interchange between meta-models is performed is the same as the one set for the user interface, namely 10'x10'. This does not mean that this is also the resolution at which the meta-models work: some of them work at a higher resolution and when calculating the results they are aggregated at the established resolution (e.g.: the agricultural and crop meta-models), others execute calculations at lower resolutions, and in order to obtain the results at the desired resolution, the resulted output for a particular region is assigned to all the cells in that region (e.g.: the hydrological sector works at river basin level).

3.5.3.2 Meta-models' inputs and outputs

The input and output variables of each meta-model had to be carefully chosen in order to simplify the algorithm. In order to select the inputs of each meta-model, the input indicators that are useful in the process of calculating the adaptation possibilities (e.g.: change in food imports) have been considered. For the prioritization of the output variables, were chosen those indicators that were considered useful by stakeholders (e.g.: coastal flood risk) but also the economic relevant indicators (e.g.: land use: urban, agricultural, non-agricultural, wooded, with pastures etc.).

3.5.3.3 Meta-models' interconnection

Through discussions between modelers and the analysis of the models that were chosen to be integrated into the platform, a series of direct links were established between the various meta-models that are presented schematically in *Figure 3.18*. The reason for which *Figure 3.18* depicts 12 sub-processes and not 10 (the number of meta-models integrated in CLIMSAVE IAP), is that the Water meta-model runs 3 times in different places of a simulation process, due to its sub-models (Hydrology, Water availability and Water Use).

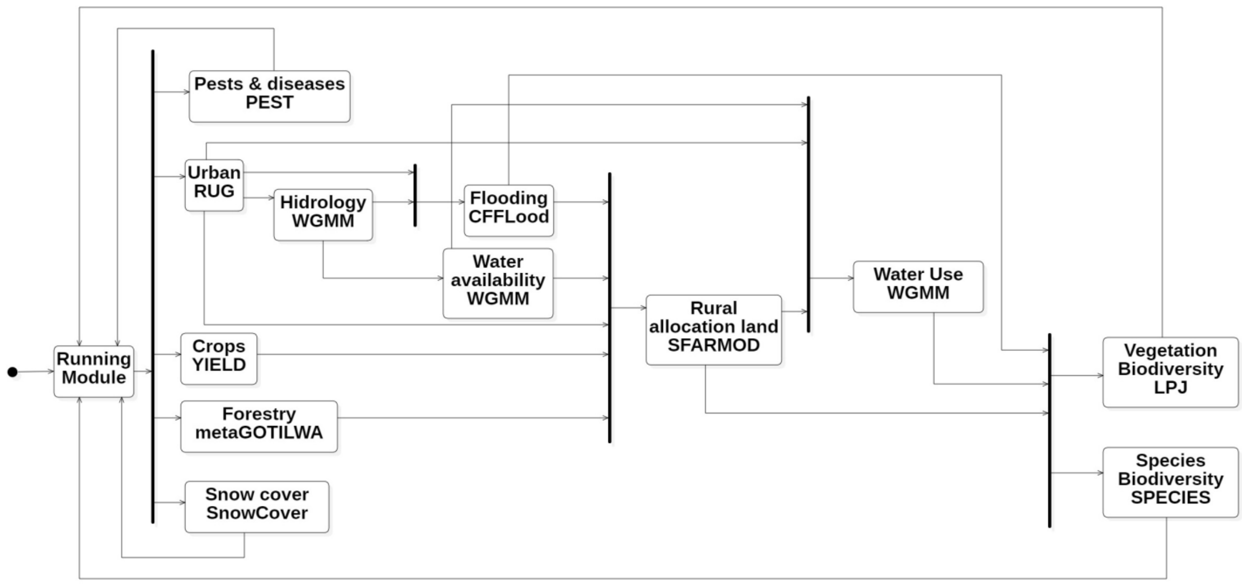


Figure 3.18 CLIMSAVE IAP meta-models execution flow (UML activity diagram)

For example, one can see how the urban meta-model through one of its output variables (artificial surface) influences the coastal meta-model (the risk of flooding of expanded artificial areas near coastal areas), but also the agricultural (terrestrial allocation) and the biodiversity one (limiting the habitats of various plant and animal species). Based on the identified links, the order of running all the meta-models in the platform was also established. As shown in *Figure 3.18* the following meta-models run in parallel:

- Urban, Snow cover, Crop, Forestry and Pests meta-models
- Species and LPJ (Biodiversity meta-models)

3.5.3.4 Data-dictionaries standardization

The data available within the integrated assessment platform can be divided into the following categories:

- Input data that have been filled in or modified by the user within the platform's input interface. These data are transmitted to the meta-models via the Running Module.
- Output data or results that have been computed within the meta-models and are displayed to the user in the graphical interface.
- Data from platform database. These data are chosen and selected according to the scenarios input data completed by the user.
- Data from internal files specific to each meta-model.
- Interchange data between meta-models in which the output of a meta-model is input to another or other meta-models.

In order to ensure the transparency of all existing data within the project, a prototype document (data dictionary) was created in which each modeler filled in the data that the meta-model needs to run successfully and the output data calculated by the meta-model. These data dictionaries were made public to all the persons involved in the project especially the modelers who identified that some of their inputs can be fed by the results obtained in other meta-models. Thus, these data dictionaries specified the following information for each variable:

- variable type: input / output
- for input data, the date source is specified:
  - from the user interface (via IAP)
  - from the platform's common database
  - from the meta-model internal files
  - from another meta-model. In this case, the meta-model name should be appointed.
- for output data, must be specified if the variable is passed to the user interface or if it can be used by other meta-models.
- the name of the variable as used in the meta-model (e.g.: Cst_event in Flood meta-model)
- the full name of the variable (e.g.: Coastal flood event)
- brief definition of the variable (e.g.: the coastal flood event - investigated by the user)
- data type: Integer, Single, Float, Double etc.
- measurement unit: meters, hectares, 1000 people
- spatial resolution: the level at which the variable is required/provided: at cell level, river basin, country, etc.

Part of a data dictionary is shown in *Figure 3.19*.

Input	Database	CORINE habitats	corine	areas of inland marsh, saltmarsh, intertidal flat	hectare	int16	Grid_cell	3	Yes	Yes
		Possible Grazing Marsh	Pasture	Possible coastal grazing marsh area within topographical bands	hectare	int16	Grid_cell	62	Yes	Yes
		Population Density	LPopDen	Localised population density for class 111 and class 112 at the baseline year	Persons/km2	Int16	Grid_cell	2	Not applicaple	Not applicable
Input	Another metamodel - UrbanMod	Residential area	RUG_Residential	proportion of the residential area	Square kilometer	single	Grid_cell	1	Not applicable	Not applicable
	Another metamodel - UrbanMod	Non-residential area	RUG_Non_residential	proportion of the non-residential area	Square Kilometer	single	Grid_cell	1	Not applicable	Not applicable
	Another metamodel - WaterGap	Change in river flow	wgmm_QMED_rltv_chng	Change in river flow for median annual flood based on daily river discharge	%	Single	Grid_cell	1	Not applicable	Not applicable
Input	User via IAP	Change in GDP	GDP_ch	Percentage change in the GDP of the EU27+4	%	Int16	Global	1	Not applicable	Not applicable
		Coastal flood event	Cst_event	The coastal flood event - investigated by the user	number of years	int16	Global	1	Not applicable	Yes (1 to 500 year return period with 1 year interval)
		Fluvial flood event	Flv_event	The fluvial flood event - investigated by the user	number of years	int16	Gobal	1	Not applicable	Yes (1 to 500 year return period with 1 year interval)
		Sea-level rise	Slr	The user-defined sea-level rise (this might be liked directly to the future climate scenario if the user doesn't define it?)	metre	single	Gobal	1	Not applicable	Yes (1 to 3 m with 0.25 m interval)
		Time slice	Time	The investigated time slice	Not applicable: 0 for baseline, 2020 for 2020s, and 2050 for 2050s	int16	Global	1	Not applicable	Yes
		Climate scenario	cl_scenario	The future climate scenario		Int16	Global	1	Not applicable	Yes
		socio-economic scenario	Scenario	The future soscio-economic scenario	Not applicable: 0 for baseline, 1 for , 2 for , 3 for , 4 for	Int16	Global	5	Not applicable	Yes
		Flood Protection	protection	The level of flood protection (No protection, minimum protection and maximum protection)	Not applicable: 0 for No protection, 1 for Minimum protection, 2 for Maximum protection	Int16	Grid_cell	3	Not applicable	Yes
		Number of Grids	Size	The total number of grids)	Grids	Int32	Global	1	Not applicable	Not applicable
		Path to the files	pathToFiles	The path to the files used in modelling	Not applicable	String	Global	1	Not applicable	Not applicable
		Flood Adaptation	Fld_adapt	Flood adaptation options	Not applicable	Int16	Global	8	Not applicaple	Yes
		Population Change	Pop	Percentage change of population	%	Int16	Global	1	Not applicable	Yes

Figure 3.19 CLIMSAVE IAP - Flood meta-model data dictionary section

After data dictionaries were completed by each modeler, they have been available online for consultation so that each modeler had the opportunity to study the files filled in by the others. Then, they corrected, if necessary, their own dictionaries with the data from other meta-model data dictionary from which it would use results. This cyclic operation finished with the completion of the exact sets of data transfers between meta-models and from or to the user interface.

The obtained meta-models were integrated with the Running Module by including them as DLLs in the form that they were created. They were developed in different programming languages.

The role of the Running Module is primarily to prepare all the data needed to run each meta-model component, whether data is received from the graphical interface, queried from the general database, or data obtained from running other modules. The Running Module feeds these data to the DLLs, runs them, and collects their results to pass them on to other meta-models or send them to be displayed in the user interface. The data transfer between meta-models is made by reference for space and transfer speed reasons.

The meta-model components can be run not only integrated, but also individually, independently of each other, thus making possible the initial testing and calibration of the meta-models. So, if one of the modelers discovers an error or inconsistency in his meta-model he can replace it without affecting the other linked meta-models. The meta-models were implemented in different ways. Some developers used neural networks (PESTS & diseases, Biodiversity-SPECIES and Forestry meta-models), others have built look-up tables using results of previous runs, obtained with more complex models on which the simplified models rely (Urban, Biodiversity-LPJ, Water meta-models), and the rest have just implemented simplified versions of the existing models (Rural land allocation, Snow cover and Flooding meta-models).

3.5.3.5 CLIMSAVE meta-models

In the following, a short description of each meta-model is provided.

3.5.3.5.1 SnowCover

SnowCover meta-model is based on the snowMAUS model [**52**] which uses as main input information on daily weather, rainfall volumes, precipitation types, maximum and minimum temperatures and places of interest elevation. The model was tested on data covering a period of several decades (1948 - 2002) in 65 regions in Austria. Results estimated with a good accuracy seasonal variations of snow level and the presence or absence of snow in these regions. CLIMSAVE includes a simplified version of this model which is suggestively called SnowCover. Compared to the initial model, the novelty of this version lies in its application across the entire Europe.

In terms of implementation, the meta-model comprises two sub-models: one that identifies regions with a snow cover higher than 3 cm and one that identifies areas covered with a layer of snow of over 10 cm. SnowCover was developed with the help of trained neural networks built and trained on the results obtained from the original model (snowMAUS). SnowCover was fully tested using a series of 12 different neural networks from which the best one was chosen in terms of variance and standard deviation.

SnowCover is not linked with other meta-models within CLIMSAVE, being a standalone running meta-model. The meta-model is provided with necessary running inputs from the climate and physical databases that include: altitude, monthly maximum and minimum temperatures and average rainfall. Output indicators are strictly related to tourism and recreational ecosystem services.

3.5.3.5.2 Urban

The urban meta-model (RUG - Regional Urban Growth) aims to estimate European urban growth based on a set of socio-economic input parameters provided by the user: change in population, change in GDP per capita, household preferences for green space/social amenities, strictness of planning constraints, attractiveness of coast and some other parameters existent in CLIMSAVE database: population, GDP per capita, current artificial surfaces, distance to coast, unsuitable areas. Explicitly the meta-model consists of a series of look-up tables containing information on the artificial surface of Europe. Depending on the input data filled in by the user when running the IAP, the meta-model produces a corresponding list of output indicators on a GIS map at a resolution of 16kmx16km. A preliminary running of the original model for all RUG output indicator combinations at a resolution of 1 kmx1 km was necessary in order to obtain the output variables. The original simulated data was aggregated and stored as look-up tables. The modelers opted for this approach as the number of input indicators was low, the storage space requirements for these tables was reasonable and the display time of results is much lower compared to running the meta-model live.

In terms of output indicators and their interaction with other meta-models the followings are mentioned: artificial surface percentage within a cell is used within the land use SFARMOD meta-model; percentage of artificial surface increase compared to the baseline is an input indicator for water use WGMM meta-model; residential and non-residential area within a cell is a variable used by coastal CFFLOOD meta-model.

3.5.3.5.3 metaGOTILWA

The forest meta-model is known in CLIMSAVE under the name of metaGOTILWA and is a simplification of the GOTILWA [**15**] (Growth Of Trees Is Limited by water) model which simulates carbon and water absorption and flows in different types of forests. Since running the original model for all forest species would have led to long computational times, CLIMSAVE opted for a model simplification. This was achieved by using trained neural networks in order to extract output indicators based on a series of input variables. 900 cells evenly spread at European level (including diverse forest types) were chosen for their training. The simulation covered the 1950-2100 period, even if CLIMSAVE provides results only up to 2050.

In terms of input variables metaGOTILWA uses climate data (monthly mean temperature and precipitation), environmental data (effective soil volume, atmospheric CO_2 concentration) and information related to existing forests (forest management, dominant tree species in the forest), having as output indicators: wood production, carbon balance, carbon stock and biomass stock. Some of these indicators are passed on to land use SFARMOD meta-model, and some are stored in the database as they are important ecosystem indicators.

3.5.3.5.4 CFFlood

CFFlood (Coastal River Flood) is the meta-model within CLIMSAVE which reviews environmental and socio-economic impacts of climatic factors in the light of flood changes that may occur in Europe in the next period. Similar to the SnowCover meta-model, CFFlood was modularly designed containing: a coastal-flood sub-model that assesses the impacts of possible flooding on coastal areas based on parameters that allow a more detailed analysis of sea rising levels and a river flood sub-model that evaluates the changes that may occur in floodplain areas. CFFlood's main output indicators are: people flooded in 1 in a 100 year event, threatened people, area at risk of flooding and damages due to flooding.

In terms of its interactions with other CLIMSAVE meta-models, CFFlood takes as input data: the residential and non-residential area corresponding to each cell (Urban meta-model), indicators of change in river courses for the calculation of flooding risk near watershed (hydrological WGMM meta-model), and passes forward output data: information about areas flooded and at risk of flooding - SFARMOD - (these areas are not suitable for intensive agriculture) and data on meadow habitats useful to SPECIES meta-model for a proper study of these areas.

3.5.3.5.5 WGMM

WGMM meta-model is built based on the original WaterGAP [**1**] model which assesses climate change impacts on water resources and consumption at European level. Since the original model has long running times the meta-model opted for reducing the number of cells from 180,000 (in WaterGAP) to 100 (in CLIMSAVE) representing Europe's major river basins. WGMM is divided into two components: one hydrological sub-model and one water-use sub-model. The hydrological sub-model aims to simulate the water cycle and determine indicators related to water availability based on look-up tables that have been run beforehand in the original WaterGAP model and aggregated to CLIMSAVE spatial resolution. Data related to water availability are calculated based on indicators such as soil type, vegetation, existent formations like: lakes, dams, nature reserves, wetlands. The water-use sub-model provides information on water consumption from a number of sectors: industrial, household, domestic, energy producing. The resulting data within WGMM refer to important indicators: river discharge, renewable water resources, ratio of water availability, total water use.

In terms of inter-linkage with other meta-models, WGMM establishes bidirectional communications with SFARMOD supplying it with the volume of water available for use in the farming sector; in turn SFARMOD sends the actual amount of water used for agriculture. WGMM also interacts unidirectional with SPECIES and CFFlood providing them with data on river flow discharge.

3.5.3.5.6 Yield

Yield meta-model is based on the ROIMPEL [**49**] agricultural model which was successfully used in other EU research projects similar to CLIMSAVE. The main advantage of the original project is that it has been tested over a long period of time and calibrated according to the changes that have appeared. This model was modularly designed in order to be used in regional and sub-regional projects that are looking for information in GIS format. Thus, ROIMPEL was run having as input parameters: terrestrial available water, soil information (type, texture, consistency), climate data (temperature, precipitation, level of radiation) and as output indicators: winter and spring wheat, winter and spring barley, winter oil seed rape, potatoes, grain maize, sunflower, soybean, cotton, grass, olives. A series of neural networks have been trained based on these inputs and outputs in order to produce the necessary results for CLIMSAVE. These results are made available to the user through SFARMOD, as it takes over Yield outputs, evaluates and calculates the crop production resulting from the above mentioned species. Thus, the user interaction with the Yield meta-model is intermediated through the SFARMOD meta-model.

3.5.3.5.7 SFARMOD

SFARMOD is CLIMSAVE's meta-model that simulates the agricultural use of land. The concept on which the meta-model underlies is the one used in the original SFARMOD-LP model [**3**] (Silsoe Whole Farm Model), namely profit estimation over time for various land use types: agricultural, forestry and unused. The decision for applying one of these types of land use is taken based on long-term evaluations of the profit brought in by each approach, while taking into account the constraints linked to soil type, precipitation level and appropriate crop type. SFARMOD simplifies the logic of the original model that takes into account a broad suite of parameters such as crop rotation, operation time and workload, agricultural mechanization, harvesting periods. The approached procedure was clustering the 23871 cells within CLIMSAVE into 182 clusters characterized by similar soil types. This approach allowed considerable diminishing of meta-model running times. Regression functions were applied on these clusters. Also, a series of neural networks have been trained on the input and output data obtained from running the SFARMOD-LP original model.

In terms of interactions with other meta-models, SFARMOD takes culture-related information suitable for each cluster from Yield and analyzes its profitability. If it exceeds a certain threshold (350 €/ha) the meta-model will opt to cultivate that crop. Otherwise it calculates the profit brought in by covering the desired area with pastures and forests. If the profit of any of these variants exceeds 120 €/ha then SFARMOD will opt for this solution. Otherwise it chooses to keep the land unused.

SFARMOD establishes communication with SPECIES to determine protected areas within a cell and assess the extent to which crops can grow on it or not. Also, as stated above, a bidirectional link is established between SFARMOD and WGMM.

3.5.3.5.8 Pest

Pest meta-model is based on the CLIMEX [**35**] model that estimates the geographical distribution of crop pest insects. The original model functions on the premise that pests are spread in areas where they have already been signaled, this aspect confirming the existence of a favorable climate in the indicated areas. Applying these observations to the model allows it to evaluate the behavior of these species in time taking into account the effects of climate change. Therefore, important data can be estimated on how climate change influences the development area and the possibility of pest population to increase in a given geographical area. The most important pest species studied in CLIMEX and the crops that they attack are: the European corn borer – corn, the Colorado potato beetle – potato, Codling moth – fruit trees, the European grapevine moth – berry fruits, the Cereal leaf beetle, the Bird cherry - oat aphid and the English grain aphid – cereals. CLIMEX was run for each of the above seven species resulting in a series of output indicators for each pest. Subsequently these results were trained and calibrated on 20 neural networks and tested on 50 iterations. Based on the obtained results, one neural network was finally chosen for each pest by considering a balance between running times and result accuracy.

3.5.3.5.9 LPJ

LPJ meta-model was built based on the results of LPJ-GUESS platform [**50**] which is in essence a global vegetation simulator. The original model calculates vegetation dynamics based on atmospheric data, water flows, plant species succession, land structure and use. The application of the original model in CLIMSAVE would have meant that a simple running for Europe to last tens of minutes. As CLIMSAVE is a real time platform, LPJ-GUESS needed to be translated into a simplified form having faster running times. LPJ output indicators: leaf area index (LAI), aboveground carbon mass (Cmass) and net primary production (NPP) are calculated based on the input data required by the original model: atmospheric CO_2 concentrations, temperature, winter and summer precipitation, but also on a CLIMSAVE parameter calculated by SFARMOD: land use percentage of each cell which is divided into: intensive agriculture, extensive agriculture, unmanaged forest and abandoned land. LPJ considers only those cells that have as land use unmanaged forest and abandoned land. For these cells the likelihood of 22 species of plants was calculated among the most popular: Cranberry, Hornbeam, Hazel, English Oak, Lime, Elm, and Cool Grass. The meta-model is based on running the original model on 65 cells that cross Europe from east to west and from north to south, thus exploring different climatic and geographical areas. A total 31500 data were simulated under all CLIMSAVE scenarios. Based on these simulations a number of transfer functions were developed to relate input and output indicators for each cell that meets the soil criteria.

3.5.3.5.10 SPECIES

SPECIES meta-model (Spatial Estimator of the Climate Impacts on the thumb of Species) [**33**] handles biodiversity in CLIMSAVE simulating climate change impacts on a suite of 111 European species that interact with different sectors such as: water, forestry, agriculture and coasts. SPECIES was designed as a suite of neuronal networks trained on a series of algorithms that relate climate (rainfall, temperature, wind) and soil input data to a suitable habitat identification for the considered species. The model results show if natural areas necessary for species survival shrink, expand or remain the same. Results are important as much attention from biodiversity scientists is directed at protecting and reducing the risk of extinction of endangered species. In order to identify the changes that may occur, SPECIES interacts with other meta-models as follows: the land use meta-model (SFARMOD) provides SPECIES with information on the arable and forest land, but also on the amount of pesticides and herbicides that can eventually damage the species living in agricultural areas; the WGMM meta-model offers SPECIES necessary information to identify suitable habitats for water loving species; CFFlood provides SPECIES with information on the coastal areas, wetlands and those sectors in danger of flooding. SPECIES calculates the presence or absence of species based on information taken from these meta-models and from the internal files.

3.6 Results

3.6.1 Results for customized scenarios

Through its accessibility, CLIMSAVE allows users to view meta-model results in real time. Reducing processing times was the main constraint for the platform to run in a short time, allowing users to view immediate results. The output data has undergone a flow of successive validation, testing and interpretation from both developers and stakeholders who have participated in CLIMSAVE. The following paragraphs present important meta-model results depicting future most probable conditions: increase in mean annual temperature and raising GDP [**44**]. For the results presented below, a series of climatic and socio-economic input indicators were customized: increase in mean annual temperature by 2.5°C compared to Baseline (0°C) and increase in GDP by 15% compared to Baseline (0%). Results show an unfavorable situation characterized by: decreasing snow-covered surfaces, shrinking forest areas, reduced water availability, restrictions of species habitats (brown bear).

SnowCover. The evolution of snow covered surface by a layer of more than 3 cm of snow due to an increase in mean annual temperature by 2.5°C was tracked for SnowCover meta-model. As expected, almost all European snow covered surfaces decrease as a result of thawing due to warmer temperatures. The quantification of this decline can be seen in *Figure 3.20*, which presents European winter sports days. A decrease is visible on the entire map, more severe in the northern and mountainous regions, as these areas store the greatest amounts of snow in Europe: in the Scandinavian Peninsula the number of days in which the snow cover exceeds 3 cm decreases by 35 to 51 days per year. These results are calculated relative to the baseline values.

RUG. RUG was tested considering a growth in GDP of 15% as a financial recovery period is expected. An increased GDP reflected in people's welfare will be further invested in the construction field due to its high profitability proven over time. Therefore, results show an increase in artificial surface (urban, rural, industrial, etc.) in the central part of Europe with percentages ranging between 0.5 and 4.6% (*Figure 3.21*). As it would be expected this increase is visible around big cities. This is graphically highlighted on the map by the green color of the regions that point out increases in artificial surface.

metaGOTILWA. For testing the forestry meta-model were chosen the same climatic conditions described above for SnowCover (increase in annual mean temperature with 2.5°C). According to metaGOTILWA the wooden areas in Central Europe will follow a downward trend up to 25,000 ha/cell (*Figure 3.22*). Similar to the results presented above, this behavior is intuitive, as increasing the annual mean temperature results in a reduction of forest species number as most of them are not high-temperature resistant. Accentuated decreases of the forest areas are visible in central Europe especially in the mountain regions.

WGMM. Under the same scenario of annual mean temperature increase by 2.5°C, water availability (output within the hydrological sub-model) is expected to decrease. Following *Figure 3.23* a decrease in water availability is recorded in most European regions. Due to the location of the river basins, the most affected areas are: UK, Austria, southern France and Germany. These regions record a decrease between 2200 million m^3 and 4800 million m^3 relative to the values recorded at Baseline.

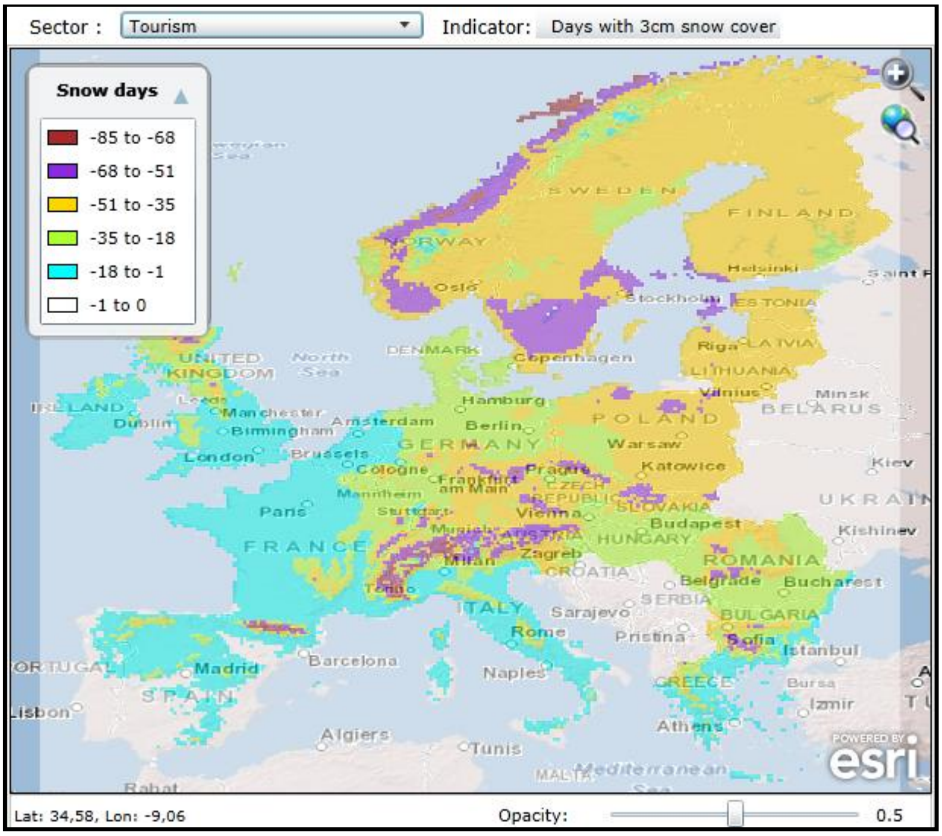


Figure 3.20 SnowCover: Days with 3cm snow cover output (Relative to baseline results)

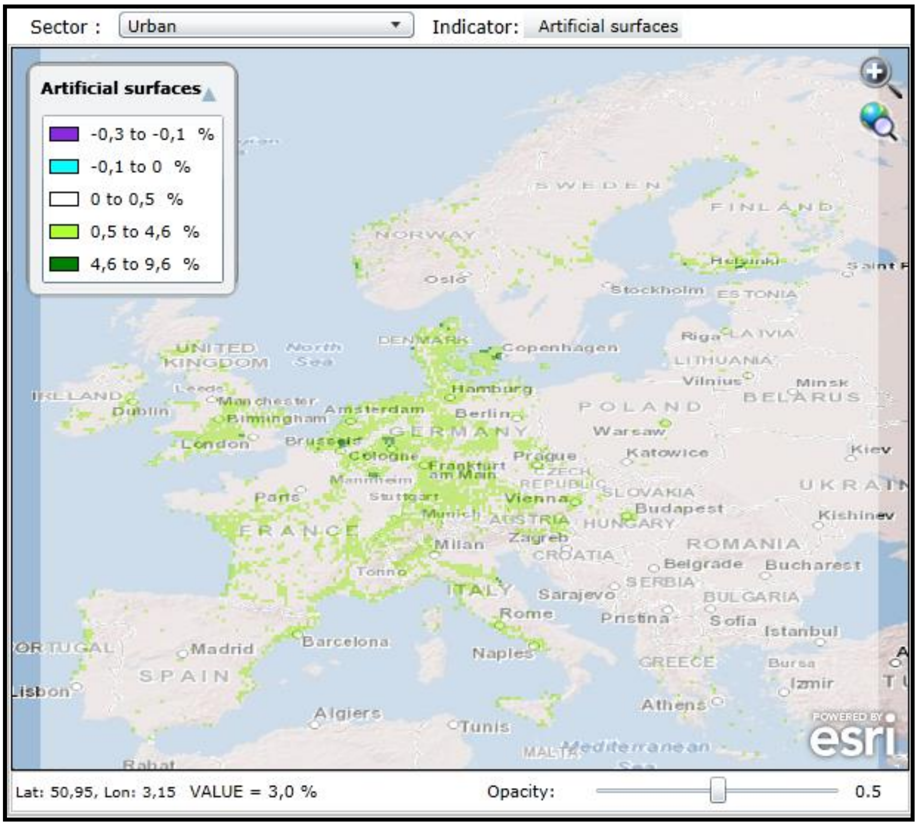


Figure 3.21 RUG: Artificial surfaces output (Relative to baseline results)

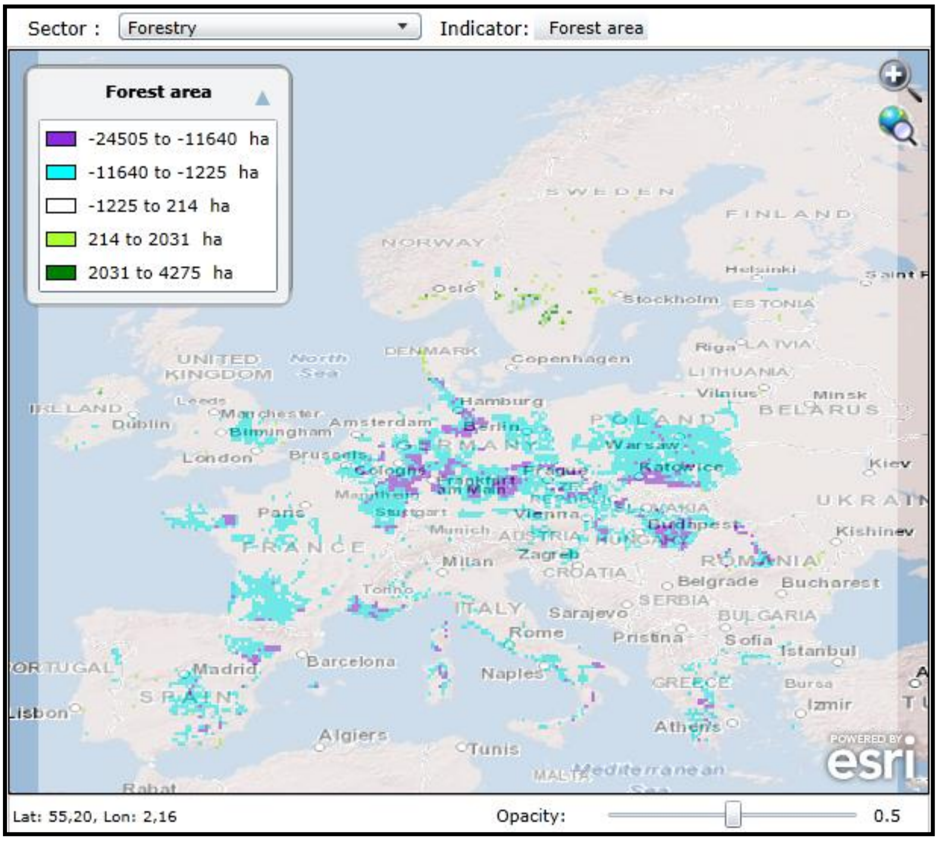


Figure 3.22 metaGOTILWA: Forest area output (Relative to baseline results)

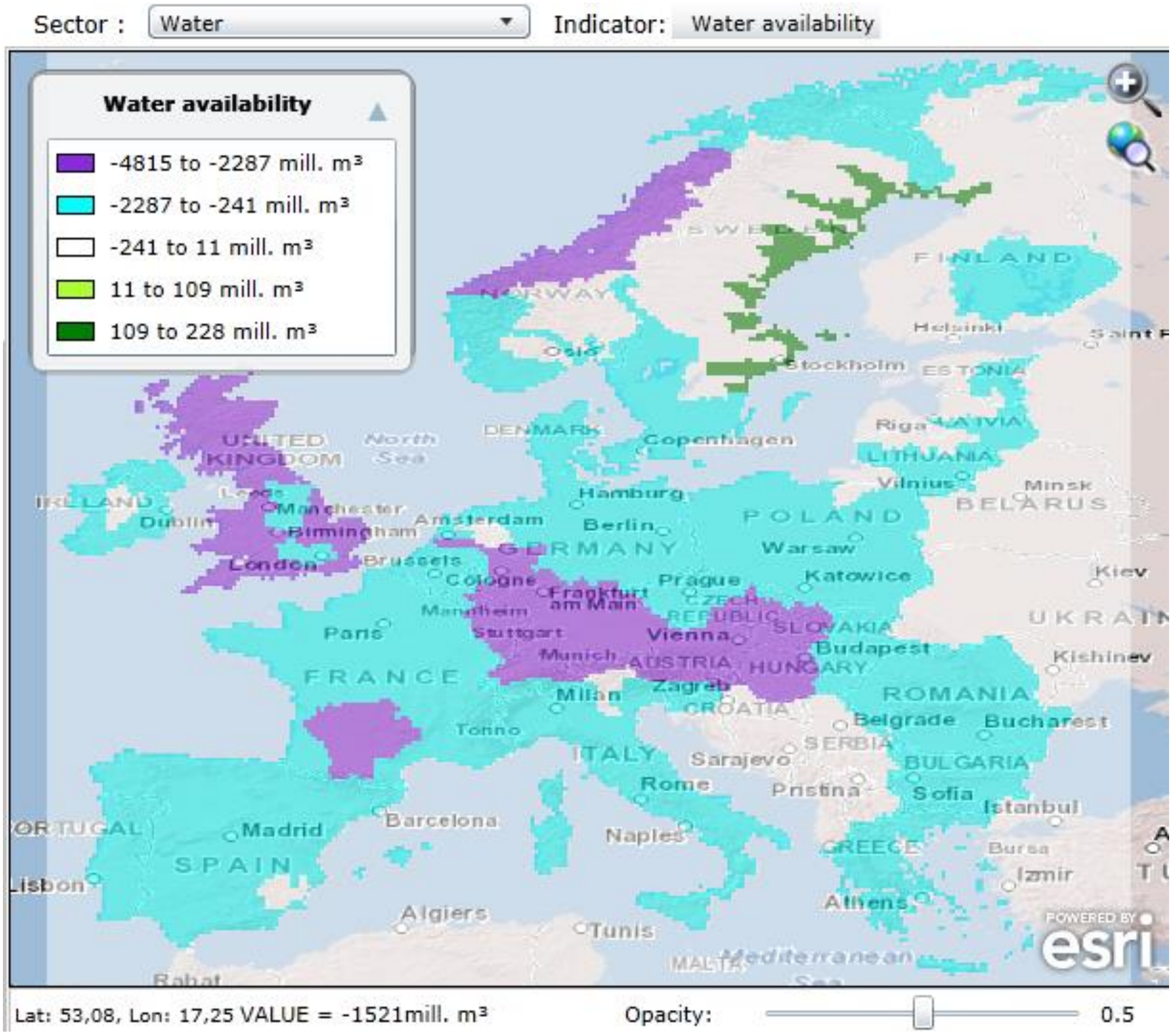


Figure 3.23 WGMM: Water availability output (Relative to baseline results)

Yield. *Figure 3.24* presents the behavior of one of Yield's indicators: sunflower. The map confirms a rising production of sunflower under a scenario of increased annual mean temperature of 2.5°C, as this plant species loves sunbathes and droughts. Therefore, if growth in southern Europe is up to 1.5 tons/ha, in the central area its productivity grows considerably with up to 3 tons/ha.

SPECIES. The biodiversity meta-model was run in the same terms of an increase in annual mean temperature by 2.5°C. The results visible in *Figure 3.25* depict habitat loss for Brown bear species especially in mountain regions, as the favorable climate for the breeding and development of this animal is a cool one without sudden temperature fluctuations.

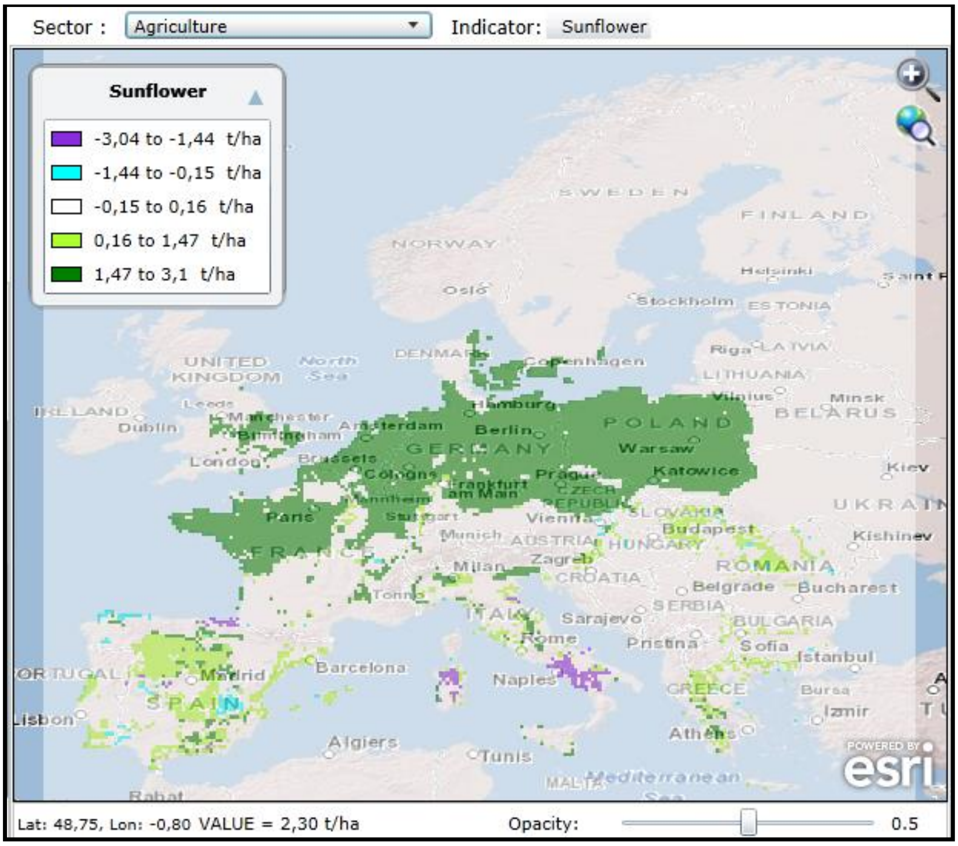


Figure 3.24 Yield: Sunflower output (Relative to baseline results)

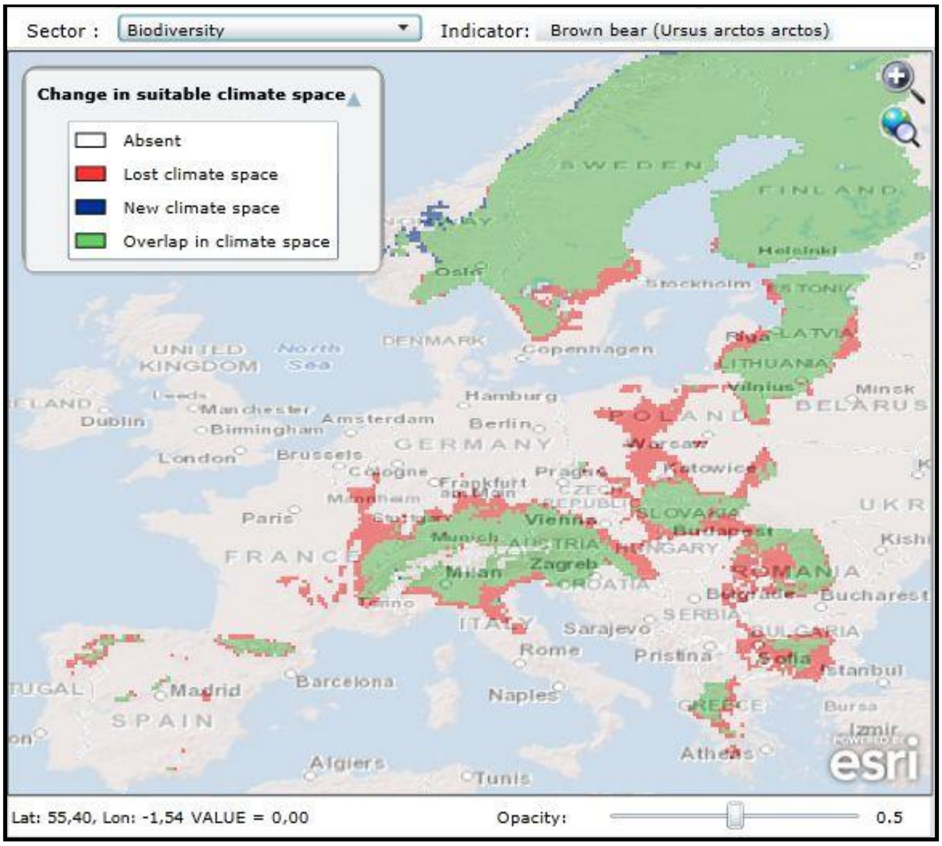


Figure 3.25 SPECIES: Brown bear output

3.6.2 Results for predefined scenarios

CLIMSAVE platform provides users a range of future predefined climatic and socio-economic scenarios which can be selected either individually or in various combinations.

3.6.2.1 Combined scenario runs

During the analysis of cross-sectorial impacts, CLIMSAVE platform was run for a number of 50 predefined scenarios combinations corresponding to the year 2050 as follows:

- 5 scenarios including climate scenarios for the 5 GCMs combined with low emissions (B1), low levels of sensitivity and unmodified socio-economic parameters.
- 5 scenarios including climate scenarios for the 5 GCMS combined with a high level of emissions (A1), a high level of sensitivity and unmodified socio-economic parameters.
- 40 scenarios comprising combinations of the above 10 scenarios with the four socio-economic scenarios.

The platform running process tracked a series of 11 output indicators out of a total of 157. The selected outputs covering different sectors are as follows:

1. area of artificial surfaces – urban meta-model output;
2. number of people flooded in a 1 in 100 year event – flood meta-model output;
3. water exploitation index – water meta-model output;
4. irrigation uptake - water meta-model output;
5. biodiversity vulnerability index - biodiversity meta-model output;
6. food production - agriculture meta-model output;
7. area of intensive farming - agriculture meta-model output;
8. area of extensive farming - agriculture meta-model output;
9. forest area - forest meta-model output;
10. area of unmanaged land - agriculture meta-model output;
11. land use intensity index – agriculture meta-model output;

Each indicator was analyzed at European and regional levels (Northern Europe, Eastern Europe, Southern Europe and Western Europe).

3.6.2.2 Cross-sectorial impacts driven by climate change

Running the above specified climate scenarios revealed that about 85% of the considered output indicators have different values compared to the baseline ones. The remaining indicators that had values similar to the baseline ones are variables that are not directly influenced by climate scenarios such as urban indicators, some reflecting food production and some related to biodiversity. In terms of regional changes, results obtained by running climatic scenarios revealed that Northern Europe is characterized by values closest to the baseline (83.6%), followed by Western and Eastern Europe. Opposite, Southern Europe is characterized by results that differ by 90% from baseline values (*Table 3.3*).

	Only Climate Scenarios	Climate and socio-economic scenarios			
		Riders	WRW	SoG	Icarus
Europe	82.7	88.2	90.0	90.9	79.1
Western Europe	84.5	90.0	87.3	89.1	86.4
Southern Europe	90.9	90.0	89.1	90.9	82.7
Eastern Europe	87.3	88.2	90.0	90.9	82.7
Northern Europe	83.6	90.0	90.9	83.6	90.0

Table 3.3 Average percentage of indicators that are different from the baseline values

European results reveal some general conclusions:

1. The urbanization process is not influenced by climatic factors.
2. There is an increase in: the number of people at risk of flooding, uncultivated land and water exploitation index.
3. A decrease is registered in agricultural areas and those covered by forests
4. Food production has divergent values with differences between -5% and +5% compared to the baseline values.

Regional conclusions are not as uniform as they are for Europe. For example, the risk of flooding is increased in most of the regions except Eastern Europe where a decrease was recorded. Also, discrepancies appeared regarding food production that in northern regions is growing due to development of agricultural regions, while in the south the indicator shows a decrease.

Biodiversity is one of the sectors heavily influenced by climate scenarios either directly or through the use of land surfaces. Biodiversity vulnerability index kept under observation in the scenario runs reveals for each region the animals that can live together in those climatic conditions and habitat. This indicator is one of the most sensitive to climate change in scenarios characterized by low emissions where the biodiversity index values are not very high.

3.6.2.3 Cross-sectorial impacts driven by combined climate and socio-economic change

In scenarios including both climate and socio-economic changes approximately 79% of the considered indicators have different values from the ones obtained for baseline. Icarus socio-economic scenario has proved to be one scenario for which values differ the least from the baseline values. This can be explained by the fact that changes in the socio-economic Icarus offsets some of the effects of climate change. The other three scenarios recorded about the same differences from baseline values at both European and regional level. Thus, if the results for Northern Europe in the case of climate scenarios were less different from the baseline, for the combination of SoG with the climate scenario this region has recorded most indicators having different values compared to baseline.

If for climate scenarios change trends seemed to follow the same direction, in scenarios that combine climate with socio-economic changes results have different directions. Thus, if in the case of climate scenarios intensive and extensive farming declined in Europe, for combined scenarios the changes ranged from declines of -8% (extensive) and -6% (intensive) to increases of 5% (extensive) and 27% (intensive). The same applies for unmanaged land areas which in climate scenarios record increases in all European regions, but for combined scenarios undergo both positive and negative changes compared to the baseline values. In terms of the urban sector, if climate scenarios have not had a direct impact on urbanization, combined scenarios influence urban development directions, which consequently determine an increase in the flood risk to which people are exposed.

Considered individually, socio-economic scenarios have different sectorial results. Thus, urban growth is greater in Riders and WRW as a result of significant increases in GDP on which these scenarios rely on. Urban growth leads to increased risk of flooding as people tend to expand urban areas in places with high risk of flooding.

In terms of use in agricultural areas SoG is characterized by an increase in intensive farming. This is due to the need to respond to the demand of food production in terms of population growth given the deficiencies of the scenario: rejecting the ideas of technological innovation that ultimately leads to a decrease in water reserves, in efficiency irrigation and last but not least diminish farm crops. As a result of these robust attempts to increase food production, imbalances occur in other areas such as forests, wild areas of land and extensive farming.

At the opposite, WRW is characterized by fairly low increases in population and different preferences in terms of food. This leads to an expansion of wild land area as the land is no longer required to practice intensive agriculture. Icarus has similar behavior as WRW in terms of land use given the presumption that population decreases, leading to a downward pressure on food production.

In terms of irrigation, both WRW and Riders use irrigation at a higher percentage than the other two socio-economic scenarios.

Surfaces covered by forests decrease in Northern, Southern and Western Europe, in all envisaged socio-economic scenarios. Eastern Europe records small increases in forested areas for Riders, WRW and Icarus. This is primarily due to profitability: in most scenarios, especially in the extreme (SoG), forests are not as profitable as agricultural areas. Also, the decrease of forested areas can be put on account of climate change that in time could lead to a change in habitat conditions in some forest regions. Following the above mentioned, forests across Europe are at risk in terms of future scenarios.

The impact on biodiversity of the combination of climate and socio-economic scenarios was one thing that was predictable. Biodiversity suffers vulnerabilities in the presence of a climate that modifies the habitat of certain species. Thus, SoG through its favoring on food production leads to increasing agricultural areas facilitating the presence of animal species living in agricultural areas that love cereals. Yet the spread of agricultural areas and thus the specific species of these regions have developed to the detriment of wooded areas and forest loving species. The results showed that the area at most risk from this point of view is Northern Europe that is likely to suffer losses of species that live in forests. However, this area is more likely to be populated by endangered species from the southern part of the continent that have high mobility and will probably relocate in the northern areas.

To conclude, the impact direction of climate scenarios tends to be better defined than the one in combined scenarios (climate changes combined with socio-economic changes). This conclusion results from the analysis of the multiple run combinations both Europe-wide and at regional level. Thus, 90% runs have shown the same direction results for future climate scenarios. For combined scenarios only 50% of the runs follow the same trend, demonstrating once again the idea that non-climatic factors have less precision concerning the future impacts [**19**]. The results also trigger an alarm regarding the importance that should be given to combined scenarios (socio-economic and climatic) and the fact that in some cases climate change may be countered by changes to the socio-economic parameters.

3.6.2.4 Validation

The results acquired from running climate and socio-economic scenarios shed light on the importance of interactions between different sectors, most of them depending on the indicators obtained in other sectors that come into contact with them. Thus, various climatic and socio-economic factors on each sector are influenced by the direction, the proportion and nature of various forces and also by inter-sectorial directive forces that can be seen following a sensitivity analysis [**22**].

A series of conclusions can be drawn related to the pattern of socio-economic scenarios as follows. The SoG scenario can be considered a winner for the agricultural sector given that all indicators regarding food production recorded substantial increases. However, increasing food production in SoG comes with some disadvantages such as decreased forest areas and wildlife, and overuse of water resources. In contrast, WRW recorded a balanced and rational use of water resources at the expense of using intensive agricultural areas. Icarus is the only scenario where there is a general decrease in urban population. As a positive outcome of this matter is a lowered risk of flooded population.

The results confirm the synthesis of IPCC on impacts of climate change [**4**]:

1. increase in agricultural areas in northern Europe, but they decrease in Southern Europe;
2. increase the risk of flooding at European level;
3. increased need for irrigation;

4. reducing water availability;
5. forest productivity growth in Northern Europe;
6. biodiversity reduction as a result of altering natural habitats, changes that are expected to lead to local disappearances of certain species and some species migrating from one region to another in search of a suitable habitat.

The undertaken scenario analysis emphasizes the importance of inter-sectorial linkages. The results show that none of the scenarios containing combinations of both socio-economic and climate changes have positive impacts on all sectors and regions. It follows the idea that there are no winners or losers, but compromise options that have identified solutions for accurate assessment of negative impacts and adaptation.

The results obtained running the CLIMSAVE platform confirm and validate once again the integrated meta-models. The advantage of this platform consists mainly in the possibility of exploring both predefined and user customized scenarios. Also, another strong point of the platform is the possibility of its use by both uninitiated people in the climate change field, and people who have interest and knowledge in this sector.

4 IMPRESSIONS DYNAMIC INTEGRATED ASSESSMENT PLATFORM

CLIMSAVE IAP is used at European level, facilitating the exploration of cross-sectorial ties on global climate change and the need to adapt, finally leading to a society with developed adaptive capacities. However, there are people, for whom a decrease of few percent in water availability is not a tragedy, being unaware of the repercussions that changes in this indicator might have in time in a dynamic environment. Therefore, an improvement of the CLIMSAVE IAP was designed and developed within the IMPRESSIONS project [**38**] – IMPRESSIONS dIAP (dynamic Integrated Assessment Platform) [**61**]. The new platform includes time-dependent meta-models that focus on tipping-points identification and exploration of high-end scenarios. The sectorial meta-models and the connections between them remained mostly the same as they were in CLIMSAVE, but in addition new models were introduced (urban, forestry and crop models) and the existing ones from CLIMSAVE have as a main objective to report if extreme limits are reached, limits from which there is no possibility of returning to a normal path. In terms of the platform running time, it increased, as meta-models run in a time-dependent approach in which they take into consideration the results obtained in previous runs. For example, if the user chooses to run a scenario for 2030 the platform starts the meta-models for 2020 and only after receiving the 2020 results will the meta-models start running for the 2030 scenario, as their run is influenced by the previous results (decadal approach). IMPRESSIONS dIAP combines CLIMSAVE IAP's accessibility advantage with a slightly longer running time (up to 30 minutes), this offset being balanced by a higher accuracy, enabling even the most skeptic users to realize the disastrous effects of climate change.

4.1 IMPRESSIONS objectives and proposed methodology

IMPRESSIONS [**38**] main goal is to study and spread the consequences of high-end socio-economic scenarios as well as to evaluate this knowledge in order to integrate them into the decisions of adapting and mitigating these consequences. In order to understand the long-term effects occurring as a result of extreme climate change, IMPRESSIONS aims to make available scientific knowledge relevant to stakeholders. The main critical scenarios considered are those which take into account future climate changes situated at the extreme limits of the possible ranges.

Although high-end scenarios are extremely plausible, there are relatively few studies or tools to evaluate their possible effects and provide solutions to reducing or adapting to these impacts. Given the fact that current methods and modeling tools meet many limitations and problems in running in terms of a disastrous scenario it appeared the need to develop a system calibrated to operate in extreme conditions, thus enabling decision-makers to have access to credible scientific information. IMPRESSIONS attempts to answer all these challenges and needs by developing an innovative research methodology that guides those interested step-by-step in the processes of representation, quantification and mapping the sectorial impacts of high-end scenarios. This new methodology resulted in the development of a web platform that is based on the methods, models and datasets developed in the best existing scientific EU research projects: CLIMSAVE, MEDIATION, ClimateCost, NeWATER, ATEAM which were developed for a single sector and not integrated with one another.

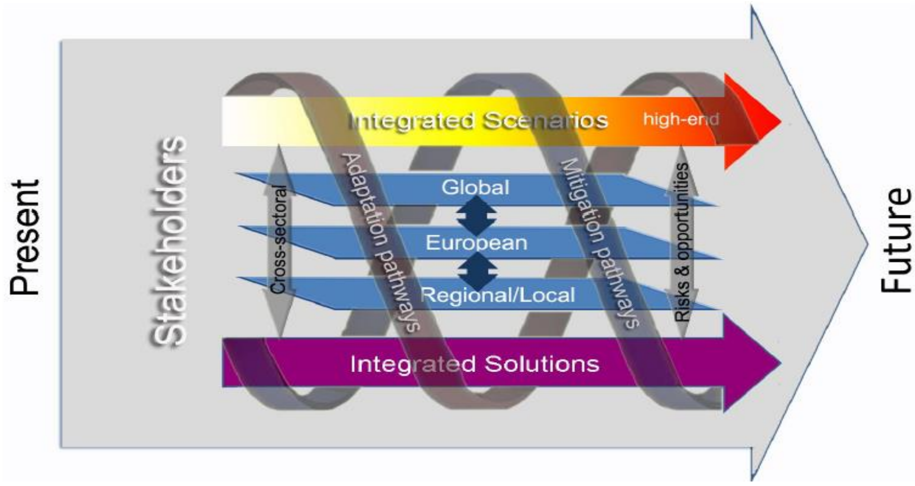


Figure 4.1 IMPRESSIONS methodology[8]

The new methodology developed within IMPRESSIONS aims to support decision-makers by identifying strategies and innovative measures in key sectors based on the assessment and quantification of risks, vulnerabilities and inter-sectorial impacts associated with extreme future scenarios. To achieve this goal the project pursued the following objectives:

- To identify the critical needs of decision-makers aiming to change their perception about high-end scenarios.
- To form a decision-making community to actively participate in identifying and defining extreme scenarios and defining ways of mitigation and adaptation.
- To define, describe and develop climate and socio-economic scenarios determined by extreme climate change.
- To apply and further develop existing methods and tools designed to quantify and understand the impacts of extreme climate change.
- To devise and develop ways of adapting to extreme scenarios.
- To disseminate data and results to communities and target groups.

4.2 IMPRESSIONS features summary

Compared to CLIMSAVE, the IMPRESSIONS methodology is based on climate and socio-economic scenarios that stretch over a wider time period (2010-2100). These scenarios are also more numerous than those in CLIMSAVE, covering a broader range of possible future conditions. The vast range of these scenarios leads to the possibility of simulating the impacts

[8] http://impressions-project.eu/

of climate change over an extended period of time including a wide palette of conditions. The web platform in which this methodology has materialized is based on these climate and socio-economic scenarios that, in order to be integrated, have been quantified and transposed into data sets.

Unlike the platform developed in CLIMSAVE, IMPRESSIONS platform has longer run times given the extended simulation period and more complex mathematical meta-models that are integrated in it. Some of these meta-models are modified and extended versions of the existing ones in CLIMSAVE, others are new models developed to be used in the new IMPRESSIONS methodology. Given the longer running times of IMPRESSIONS platform, it will not have quick response time as the CLIMSAVE platform. The user will receive an e-mail at the end of the run with a link at which results can viewed and downloaded.

The main features of the IMPRESSIONS platform are:

- delayed response times
- online availability [**61**]
- ease of use
- available at any time
- developed with the help of state-of-the-art web technologies and architectural patterns
- no additional software installation needed
- integration and interconnection of climatic and socio-economic scenarios developed until 2100, not just Baseline, 2020 and 2050 (CLIMSAVE IAP):
    - climatic scenarios:
        - baseline period is 1981-2010
        - 10-year climate periods (2010-2020, 2020-2030 ... 2090-2100)
    - socio-economic scenarios:
        - baseline year is 2010
        - quantification of socio-economic variables is done for periods of ten years by interpolating the existing values for the years 2010, 2040, 2070 and 2100
- simulation of a large scale of impact indicators from different interest sectors: urban, water, agriculture, forests, coasts, land use and biodiversity
    - uses the meta-modeling approach, even if it does not have the same time restrictions as CLIMSAVE IAP, as for some of meta-models, running the original models, on which they rely on, would take for days in a row.
    - integration of 7 sectorial meta-models
    - modular architecture, enabling the replacing of meta-model components with new or improved versions
    - meta-models that run in a time-dependent manner, saving previous results and calibrating the new ones based on them [**47**]

  - o decadal running of the sectoral meta-models and taking into account the outcomes and the climatic and socio-economic conditions from the last decade, simulating emerged impacts and possibilities of adaptation.
- results are available at the end of the scenario simulation run which might take over 30 minutes. At the end of the run, the user receives an e-mail with a link at which he can access the Output Interface and inspect and download the results.
- each output variable has a number of 24131 values which stands for the cell numbers represented on a GIS map, that is a value for each cell. This number was calculated based on dividing Europe into cells of 10`x10` (~16 kmx16 km.) The layout is similar to the one used in CLIMSAVE IAP the difference standing in the inclusion of Malta and Croatia on the map.
- more accurate results that the ones obtained in CLIMSAVE IAP due to the more complex meta-models integrated
- identification of tipping-points (points from which there is no turning back to normality)

Even though due to these new characteristics the new platform has longer running times than other online platforms, it still benefits from the advantages of the original models that it is based on.

4.3 Progress beyond state of the art

Although lately climate change is considered one of the most disruptive processes for the environment and society, its production and effects bring the decision-making process to another stage, inducing a new level of uncertainty. Aware of these issues, decision-makers often fail to put in balance these future climate scenarios, fact which is most likely led by an unsuccessful dissemination of knowledge in the climate change field [**8**]. Although methods and techniques have been developed to quantify the uncertainties introduced by climate change most often they are not applied. All these arguments reinforce IMPRESSIONS methodology aim, namely the development of a reliable platform to help decision institutions.

Over time numerous platforms have been designed to help and guide decision-makers to build policies and strategies in order to take and apply decisions. The information provided by these tools can often be visualized in local platforms such as: Danish Adaptation Platform [**63**], the UK's Climate Impacts Programme [**64**], Germany's Competence Centre on Climate Impacts and Adaptation [**60**]. However, the available information and platforms were conceived and designed for predictable situations and not for high-end scenarios which are largely characterized by major changes (e.g. 2°C increase in annual mean temperature cannot be compared with a rise of 4°C). This is a field in which IMPRESSIONS methodology innovates by conceiving and quantifying climate and socio-economic scenarios that also include the potential extreme situations that may arise in the future.

- IMPRESSIONS brings novelties in terms of climate and socio-economic scenarios [**17**] by combining them according to the IPCC Fifth Assessment Report [**25**]. Although integrating these types of scenarios is an unexplored area so far.
- IMPRESSIONS analyzed current existing linear scenarios and shaped the idea of high-end ones by studying and integrating the critical points at social and climatic level.
- IMPRESSIONS scenarios were developed with the help of stakeholders. By engaging them, the new scenarios within IMPRESSIONS methodology are credible and are designed to cover the period from 2010 until 2100. As a novelty in IMPRESSIONS, stakeholders were involved in every stage of project development and research by providing a continuous process of collaboration and learning from the conceptual parts of scenario definition to the validation of the final results.
- IMPRESSIONS methodology is conceptualized and materialized into an online delayed response platform (IMPRESSIONS dIAP - dynamic Integrated Assessment Platform) designed as a continuation and reinvention of CLIMSAVE Integrated Assessment Platform (IAP), by adding a number of improvements and adjustments to the CLIMSAVE platform.
- This new platform can be used to answer questions concerning multi-sectorial changes that take place in climatic and socio-economic future conditions. IMPRESSIONS dIAP aims to overcome the barriers of linear multi-sectorial analyzes by combining a series of sectorial meta-models of interest that run in a time dependent manner.
- The results cover a vast range of inter-connected sectors: urban, agriculture, forests, flood, biodiversity and water sector.

4.4 IMPRESSIONS scenarios

One of the main purposes of dIAP is to quantify and explore the risks and impacts arising from the critical scenarios (high-end scenarios) that are increasingly imminent [**41**]. These critical scenarios were defined within the project as those scenarios characterized by quantifications of climate change that reach the upper limits of possible future values such as values for temperature increase above 2° Celsius (maximum value set by the EU and the UNFCCC (United Nations Climate Change) as the limit above which the temperature will irreversibly impact the environment) or socio-economic scenarios that include high levels of emissions.

Thus, IMPRESSIONS has proposed the development of a research methodology to create and integrate these critical scenarios within important key sectors with the help of stakeholders. These high-end situations were modeled using climate and the socio-economic scenarios elaborated with the help of representative concentration pathways (RCPs) and shared socio-economic pathways (SSPs). These types of scenarios were chosen over others as being developed recently and having a time horizon which may extend until 2100.

Climate scenarios include RCP 4.5 and RCP 8.5 (also adopted by IPCC) covering two trajectories of greenhouse gas concentrations (4.5 and 8.5 W/m^2) and a vast range of temperature growth (2 - 6° C) required by the simulation of high-end situations:

- RCP 4.5 - emissions increase until 2040 and then follow a downward trend
- RCP 8.5 - emissions have an upward trend until 2100

Regarding the climate models used to simulate future climatic conditions, combinations of global climatic models (GCMs) and regional climatic models (RCMs) were chosen, using only those global models that were downscaled in the Coordinated Regional Downscaling Experiment (CORDEX) [**56**].

The socio-economic scenarios concern social issues such as demography, economic, social and technological factors but also environment and governance. The figure from Annex 3 encloses the four scenarios in a representation based on the inequality level and GDP that characterizes them. Within IMPRESSIONS the narrative descriptions of these scenarios were quantified in order to meet the needs of the integrated assessment platform.

4.5 Platform design and implementation

Unlike fast response platforms, delayed response platforms are not time limited and can integrate embedded models that can be more precise and complex, responding better to user requirements, but requiring a longer runtime and response.

These platforms can evaluate temporal and spatial dependencies of adaptation as well as risk mitigation taking into account the complexity induced by nonlinearity and the critical points described in the scenarios.

IMPRESSIONS dIAP (dynamic Integrated Assessment Platform) is such a platform and [**61**] is built starting from its predecessor - CLIMSAVE IAP - which offers the possibility of simulating European impacts of climate change at cross-sectorial level, identifying vulnerable areas and options for adaptation. However, IAP is an interactive platform available online with quick response that aimed running speed. In this context the series of sectorial models included in IAP opted for a meta-modeling approach. Therefore, complex models for the key sectors included in the IAP have been simplified and turned into meta-models in view of reduced running times. IMPRESSIONS dIAP is a platform with delayed response with longer running times, more complex meta-models and more accurate results compared to the ones in CLIMSAVE IAP.

4.5.1 Client-Server architecture

IMPRESSIONS dIAP is built on **Client/Server** architecture following the same idea as in CLIMSAVE IAP, keeping in mind the advantages of accessibility, scalability and the possibility of upgrading the platform whenever it is needed.

Although the type of architecture used for IMPRESSIONS dIAP remained the same as in CLIMSAVE IAP, its application within the platform was different. Unlike CLIMSAVE IAP where the running time was crucial and where the inputs and outputs displayed to the user followed one after the other, in dIAP running the meta-models on the **Server** takes longer due to their higher complexity and decadal running. In dIAP the **Client** includes two user interfaces: the Input and Output Interfaces of the platform and the **Server** the computational component. The user interaction with the platform is not a real-time one, as the two interfaces (Input and Output) are not interconnected.

IMPRESSIONS dIAP platform architecture is synthesized in *Figure 4.2*.

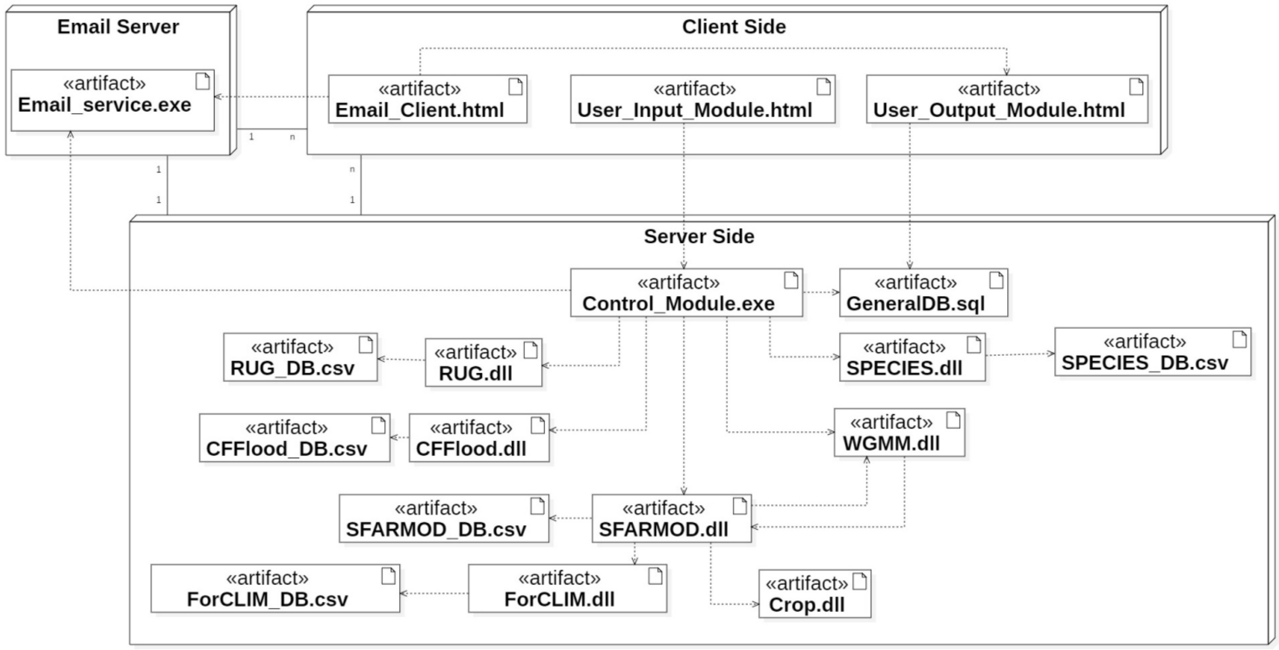


Figure 4.2 IMPRESSIONS dIAP architecture (UML deployment diagram)

The computational solutions for both **Server** and **Client** have changed for dIAP.

The **Client Part** including User Input Module and User Output Module has been developed with web technologies including HTML, CSS, Javascript, JQuery. These technologies have been widely used given their vast spread, ease of use and updating, availability of running in any browser.

The two graphic components interact with the user as follows:

- **User Input Module** - the component through which the user can start running the integrated platform after selecting the necessary input scenarios and indicators. This module captures user inputs specific to each meta-model and sends them to the **Server**.

- **User Output Module** - the graphical interface component to which the user has access to via the e-mail link received after the meta-models have finished running. Through this interface, the user can view in an interactive manner the output indicators corresponding to the integrated sectors plotted on a GIS map with a resolution of 10'x10' grid organized in a total of 24131 cells. The results viewed on the map are saved on the **Server.**

The artifacts on the **Server** are:

- dIAP central database that stores the climatic and socio-economic datasets and other data needed for running the meta-models. The database is a Microsoft SQL database containing 22 tables:
    - 12 climatic tables – precipitation, temperature, radiation, CO_2, sea-level rise
    - 4 tables containing socio-economic quantifications for each indicator in the User Input Interface
    - 6 tables containing particular data necessary when running the meta-models (e.g.: GDP, Saltmarsh, Land areas).
- Sectorial meta-models which were designed as DLLs (Microsoft Dynamic-Link Libraries). Some of them use their own files to store internal data, some are fed with information from the general database and some meta-models establish direct links with each other.
- The Control Module (*Figure 4.2*) is the executable module running on the **Server.** It was implemented in ASP .NET Framework. The programming language that was used is C#. It receives the requests from User Input Module, analyses them and interrogates the database to extract the main information needed to run the desired simulation. Next, it prepares the data for the meta-models, runs them in an optimized way according to the default flow, stores the results in the database and sends the user who initiated the run an e-mail with the link where results can be viewed or downloaded.

The technical specifications of the **Server** on which IMPRESSIONS dIAP is running are as follows:

- Operating system: Windows Server 2012 R2 (64 bits)
- CPU: Intel(R) Xeon(R) CPU E3 - 1230 v5 @ 3.40GHz 4 Cores
- RAM: 32GB (DDR4)

Using the platform consists of three steps:

1. First the user selects the preferred climatic and socio-economic scenarios. According to the chosen scenarios the user can also modify the input variables specific to the meta-models integrated within the platform. This choice can be made in the User Input Module which then submits the information to the **Server**.
2. The Control Module on the server performs the following:

   a. processes the input data received from the User Input Module
   b. queries the GeneralDB (*Figure 4.2*) for the data that are needed
   c. runs the chain of meta-models
   d. stores the output data in the GeneralDB
   e. notifies the user by e-mail that the run was completed and how he can access the results
3. Users can graphically view on a GIS map the results by accessing User Output Module via the web address received by e-mail or directly download the results that they are interested in.

4.5.2 Control_Module detailed design

The Control_ Module component is responsible with the interconnection of the meta-models. *Figure 4.3* presents its class diagram. The relations between classes are unidirectional associations.

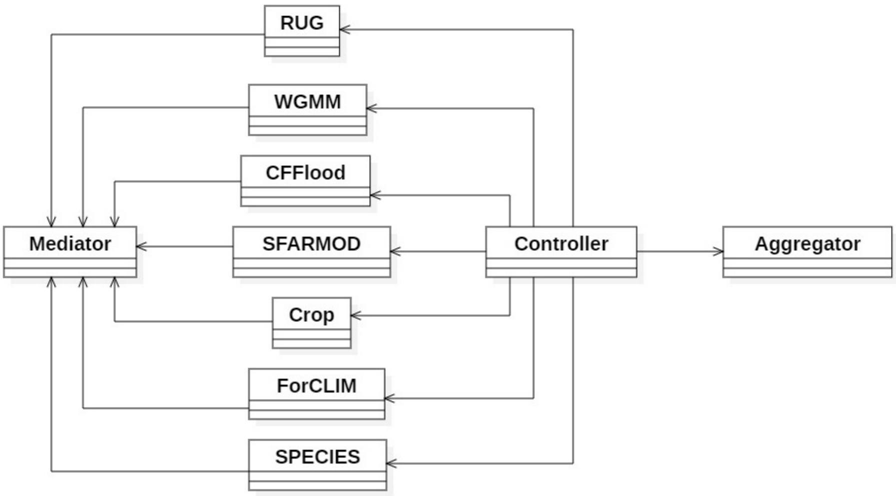


Figure 4.3 Control Module class diagram

- The Mediator object contains the data that are interchanged between meta-models. For example an output indicator of the urban model: Artificial Surface which is used by the Flood meta-model is stored in the Mediator in a variable called RUG_CFFlood_Artificial_Surface. In this case “RUG” stands for the source and “CFFlood” for the destination meta-model of the indicator. “Artificial_Surface” is the name of the variable that is being passed from RUG to CFFlood. All indicators that are interchanged between meta-models follow the same pattern as the one described above.
- The 7 classes at the center of the diagram depicted in *Figure 4.3* (RUG, WGMM, CFFlood, SFARMOD, Crop, ForCLIM and SPECIES) correspond to the meta-models in IMPRESSIONS dIAP. The meta-model objects resulted from the instantiation of each of the 7 classes execute the following sequence of operations:

  - readMediator() – populates the input indicators of the meta-model with data from the Mediator
  - useMetaModel() - runs the DLL. The function reaches the end only after the meta-model finishes its execution. In the event of an error, the function returns the error.
  - writeMediator() - populates the Mediator with the meta-model's output indicators that will be further used by other meta-models.
  - getResult() – stores the results obtained at the end of the meta-model run in the database.
- The Controller object (*Figure 4.3*) receives the data filled in by the user via the User Input Interface and creates an Aggregator object in which it stores these data. It creates and initializes the Mediator object, then it creates the meta-model objects, passing to each one a reference to the Mediator. Next, in each decade, the Controller object takes from the Aggregator the user input data required to run the meta-models in that decade and populates the Mediator with them. At the end of the simulation the Controller sends an e-mail to the user with a link where results can be viewed and downloaded.

4.5.3 Designing IMPRESSIONS dIAP Graphical User Interface

4.5.3.1 GUI requirements

The experience from CLIMSAVE IAP and the support of the IMPRESSIONS participants helped determine the elements and characteristics that should be included in both Input and Output Interfaces:

- Similar to CLIMSAVE IAP, IMPRESSIONS dIAP should be easy to interact with to introduce, visualize and download the results.
- The user should have the possibility to run predefined scenarios or a customized scenario by modifying input parameters.
- The platform should provide explanations and guidance on the parameters that can be modified and the intervals between which these changes are allowed and their structure according to the sectors they are part of.
- In terms of running time, IMPRESSIONS dIAP has run times longer than CLIMSAVE IAP: a full run can take up to 30 minutes. This is primarily due to the nine decades period for which the platform is run. Another reason is the increased complexity of some meta-models compared to those in CLIMSAVE IAP, effectively storing the results into the database from where they can be later viewed through the Output Interface. In CLIMSAVE IAP results were stored in the internal memory of the platform, which was released when the user left the platform. For IMPRESSIONS dIAP results remain stored on the server for a longer period and are available for longer time (3 months).

4.5.3.2 GUI implementation

To meet the above requirements the user must be able to perform the following in the Input Interface:

- choose the scenario:
  - climatic:
    - Representative Climate Pathway: Baseline, RCP 4.5 or RCP 8.5
    - Global Climate Models (GCM) / Regional Climate Model (RCM): GFDL-ESM2M_RCA4, HadGEM2-ES_RCA4, MPI-ESM-LR_CCLM4, CanESM_CanRCM4, IPSL-CM5A_WRF
  - socio-economic: Baseline, SSP1, SSP3, SSP4 or SSP5
- run the platform both in an integrated manner or standalone (only one meta-model).

Figure 4.4 illustrates the evolution of the Input Interface from conception to the final version.

The novelty brought by the dIAP platform consists especially in the simulation time of the meta-models and their dynamics. So, if its parent – the CLIMSAVE IAP platform - can simulate the effects of climate change for one moment of time, be it the current (Baseline), 2020 or 2050, dIAP runs dynamically for nine decades (2010-2100). This dynamic consists in the fact that the meta-models can take account for the values obtained in past decades either by themselves or by other meta-models with which they interact.

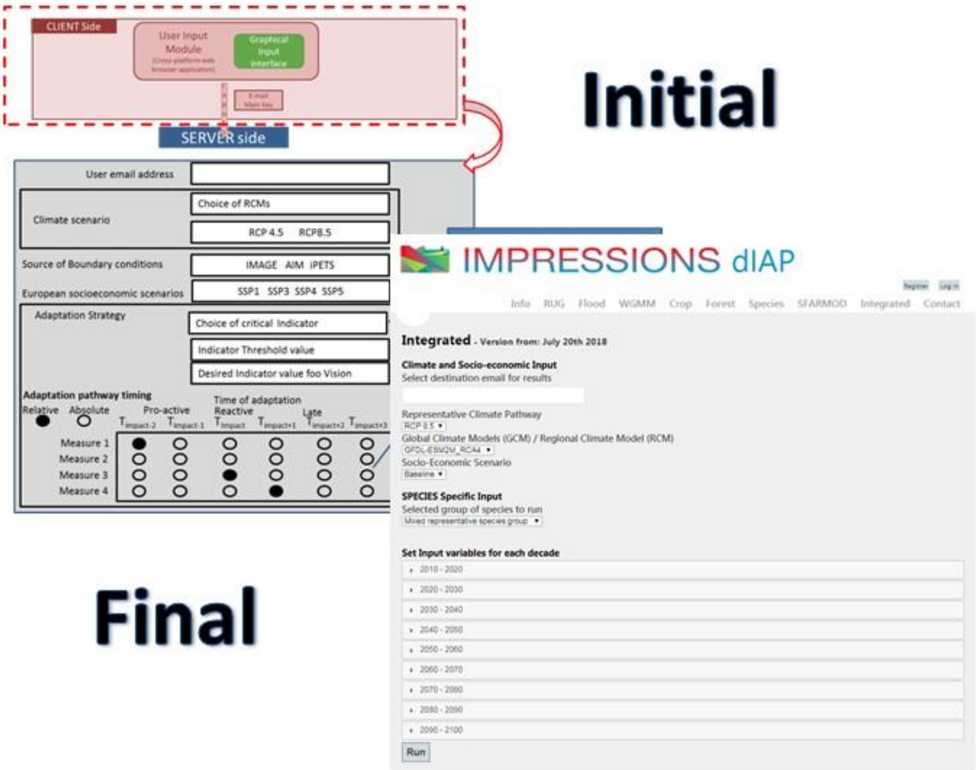


Figure 4.4 IMPRESSIONS dIAP User Input Interface progress

Below are presented IMPRESSIONS Input and Output GUIs, how can they be used and the features provided by them.

4.5.3.3 User Input Module

Info Tab – By accessing dIAP's web address [**61**] the information page is the opening web page. It presents the latest changes/updates in dIAP. The page can also be accessed by clicking the Info button (*Figure 4.5*).

Figure 4.5 IMPRESSIONS dIAP - User Input Module – Info Tab

Standalone model Tabs – Each meta-model from dIAP can also be run standalone for meta-model validation purposes. Each meta-model has a designated page for this functionality which can be accessed by clicking the correspondent button from the upper menu. In *Figure 4.6* is depicted as example the Flood meta-model which can be run standalone and for which a series of input variables can be modified.

dIAP Integrated Tab – can be accessed from the *Integrated Tab* in the menu. In this running mode meta-models run all together in the agreed order, feeding each other the inputs and outputs that they need. They run for nine decades and each run lasts for about 30 minutes. This is why the results will not always be available in real time (depending on the number of users that are running) but the user will be informed via e-mail at the end of the run. This is why the user is supposed to fill in his e-mail address at the beginning of the run. There are two ways of running Integrated dIAP:

- A simple one (*Figure 4.7*) in which the user can select the preferred RCP, GCM/RCM and Socio-economic scenarios. Based on the selected scenarios and on the quantifications stored in dIAP's internal database, the meta-model input variables are fed with the correspondent values. By clicking the run button, Integrated dIAP starts running and 30 minutes later (approximately) the results will be available.

- A more complex one in which each input parameter of each meta-model can be modified by the user via a slider or a text field. *Figure 4.9* presents an example on how the user can modify the input values for WGMM for the first decade. To do this the user has to expand the "2010-2020" accordion by clicking explicitly on the desired decade. A list with all the meta-models for which input indicators can be modified will appear. By expanding the accordion of the meta-model for which the user wants to customize an input indicator, in this case "WGMM", a list with all input indicators for WGMM will appear. Further, the user can modify the desired input indicator for the meta-model and decade that he has chosen. The modified values are then fed to the meta-models after clicking the Run button.

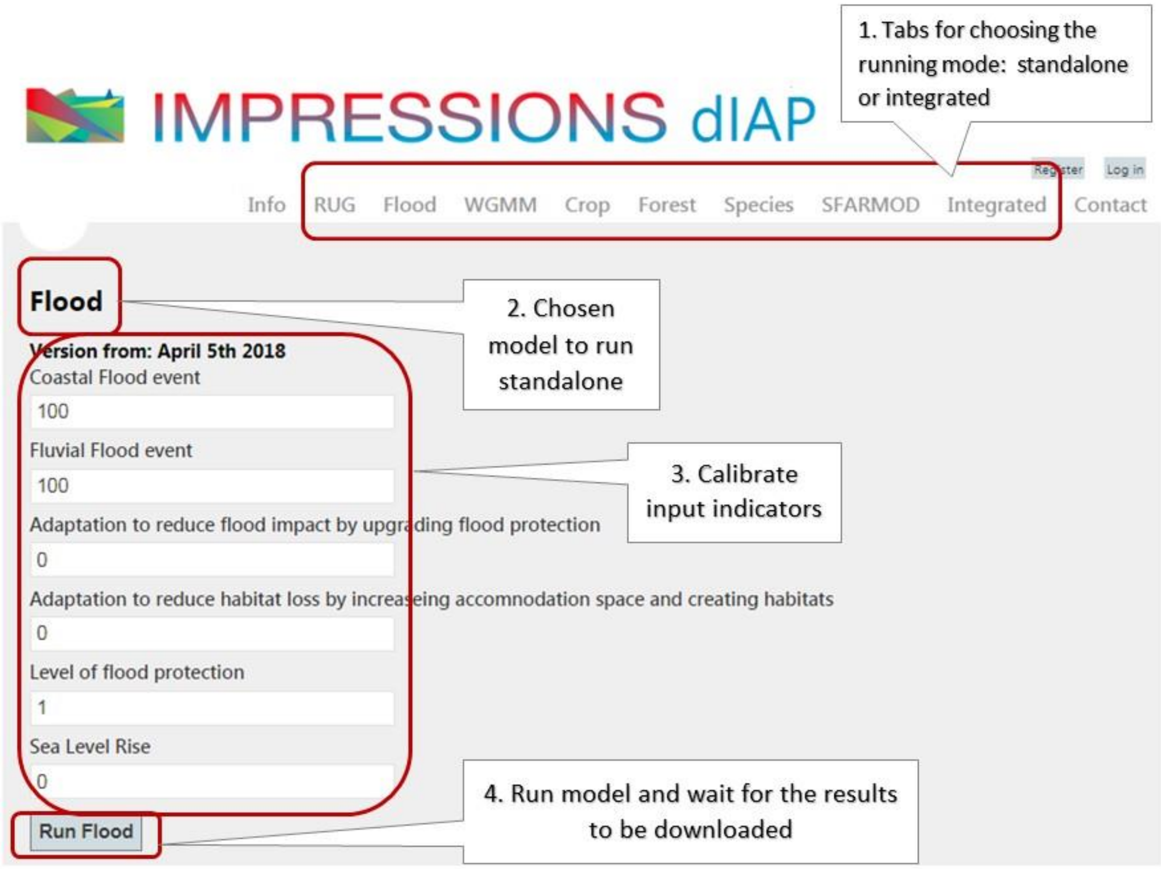


Figure 4.6 IMPRESSIONS dIAP - User Input Module – Flood standalone Tab

After clicking the Run button, a message is displayed in which the user is informed that dIAP started running and he will receive an e-mail at the end of the run. The user is also given the possibility to view the partial results by clicking the "here" link (*Figure 4.8*). By clicking this link a new page opens – dIAP Output Interface, in which for the first 2-3 minutes he is not able to see anything as no results are available yet. After around 2 minutes the first results will be available and the user will then be able to inspect them on the map.

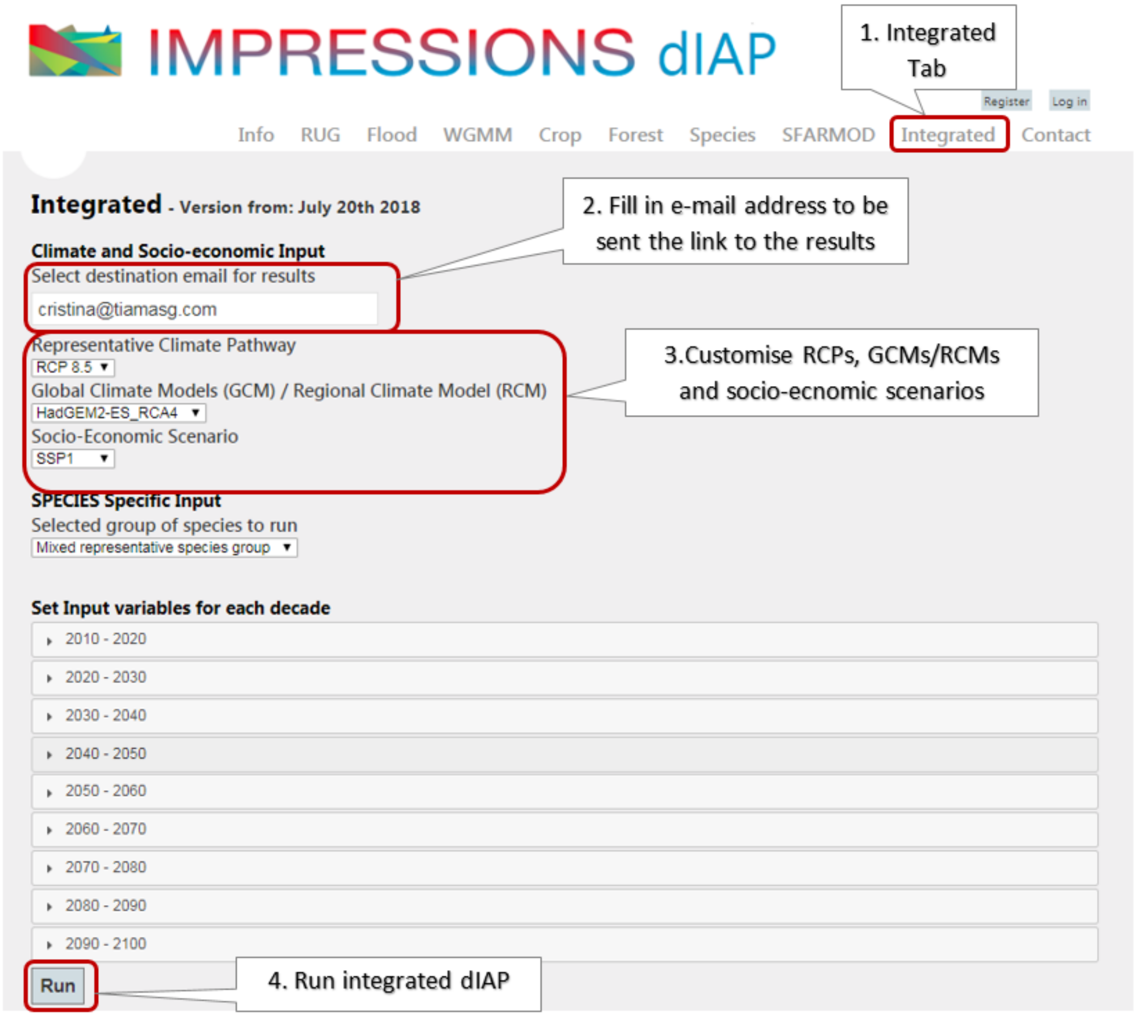


Figure 4.7 IMPRESSIONS dIAP - User Input Module – Integrated Tab – simple run

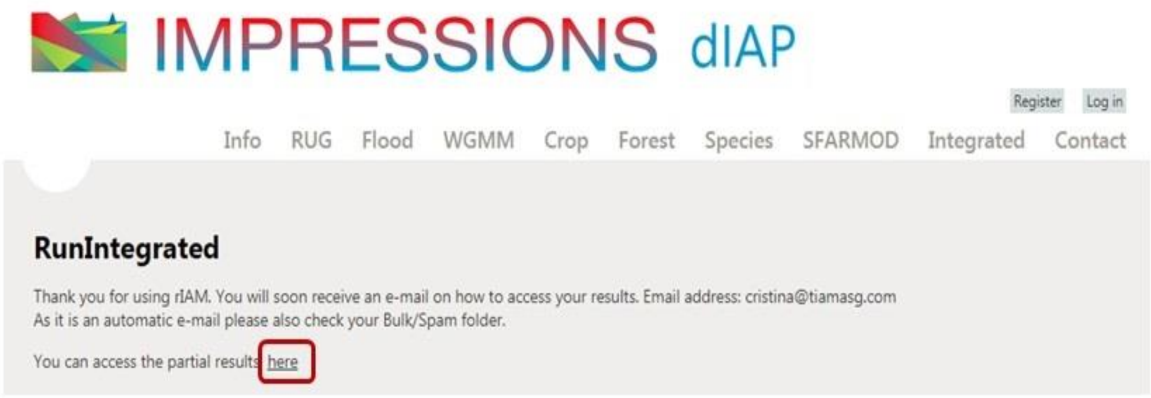


Figure 4.8 IMPRESSIONS dIAP - User Input Module – message to confirm run started

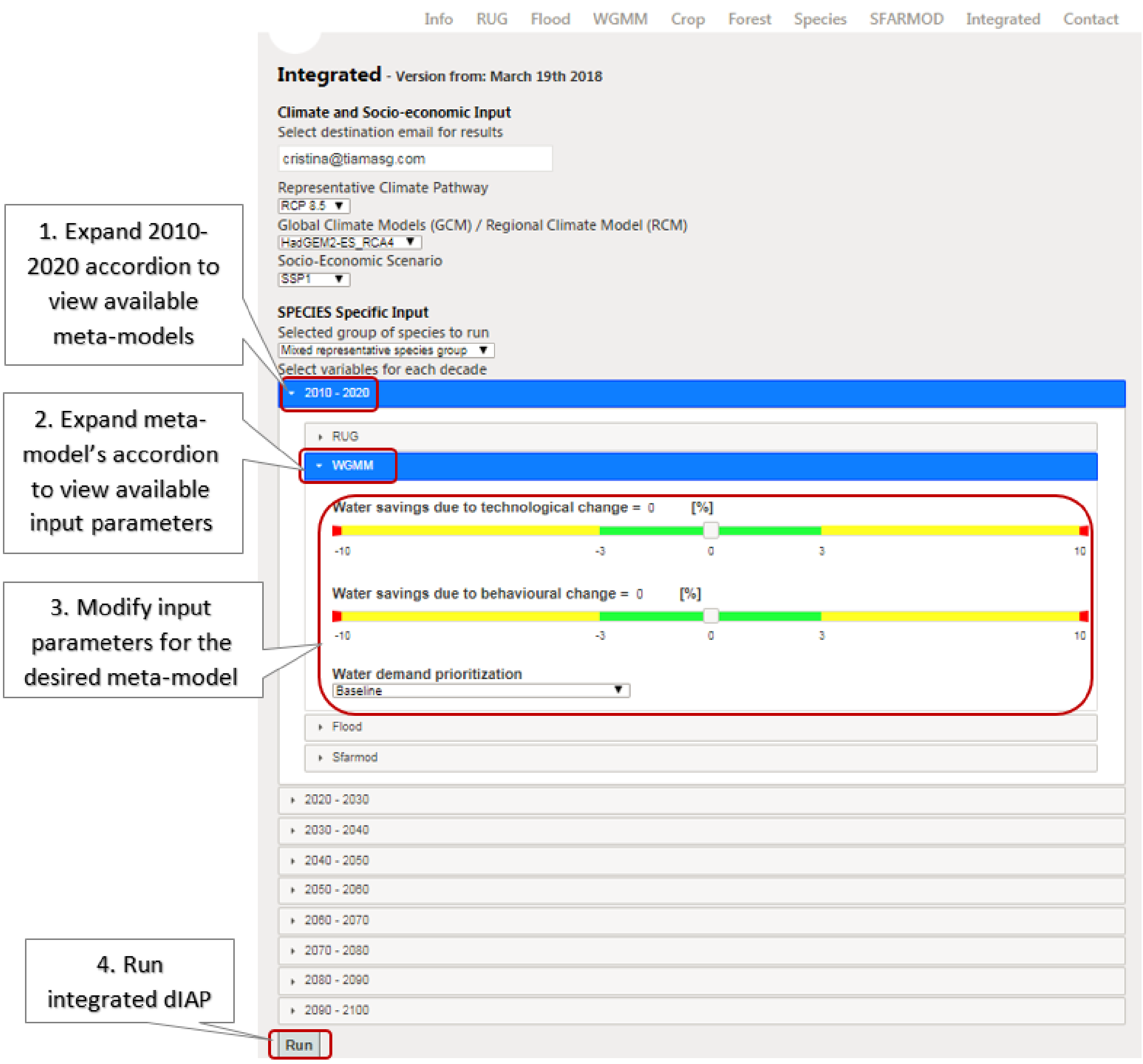


Figure 4.9 IMPRESSIONS dIAP - User Input Module – Integrated Tab – complex run

4.5.3.4 User Output Module

Map results display:

- ***Map visualization*** (*Figure 4.11*) - In the upper part of the page a decadal arrow bar is present through which the user can move and see the results for an indicator in all 9 decades. The red zone on the bar depicts the decade for which the indicators are displayed at the moment. The blue colored zones represent the decades for which results are also available and can be explored and the grey zones are the decades for which results are not available yet. The next section shows the general information and scenarios under which Integrated dIAP was run. A more extended list of input values that have been fed to the meta-models are available by clicking the "See all inputs and description of outputs". This page (*Figure 4.10*) also presents the output variables that are obtained for each meta-model. By clicking the "Back" button he can return to the previous page.

In terms of outputs he can choose what type of indicators he wants to inspect (Sectoral/Ecosystem service) and from which Sector. If he chooses the Biodiversity sector he is also given the possibility to choose the Species that he wants. In the end, the user can choose the indicator that he wants to inspect on the map. Other facilities that are available in the Output Interface are the “Loading bar” (*Figure 4.11*) which shows how many output files have been created and how many are left to calculate. In terms of maps facilities: similar to CLIMSAVE IAP the user can view the value of the selected output indicator for each cell on the map. Also, changing the opacity of the map is a functionality that was included. *Figure 4.11* presents the above listed features.

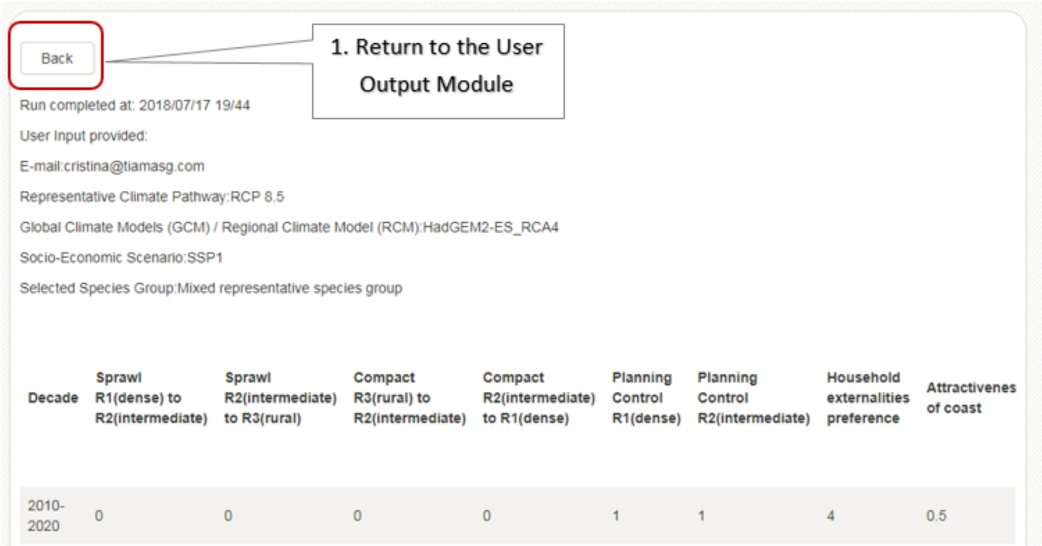


Figure 4.10 IMPRESSIONS dIAP - User Output Module – input/output indicators section

- ***Legend section*** - Changing the legend (*Figure 4.12*) is also an important aspect of the Output Interface functionality. A “Set legend” button is available in the lower part of the Legend section at the end of the run. By clicking the “Set Legend” button a Legend properties pane is displayed, in which the user can view the minimum and the maximum values of the output indicator that he chooses to inspect. At the beginning, the outputs are organized in 6 classes (equally distributed between the minimum and the maximum value) and displayed under a default color palette. As functionalities, the user can manually change the color of each interval or automatically by changing the color ramp. Also, he can manually change the number of classes in which the values are split (he has to manually set the limits of the intervals) and the number of digits of each interval. If after modifying the legend properties, the user wants to keep this legend as default he can do this by ticking the “Set as default” functionality. The user also has the possibility to save the legend that he created and reuse it later by importing it.
- ***Decadal animation*** - After the end of the run it is very interesting to inspect the changes that many of the indicators suffer across decades.

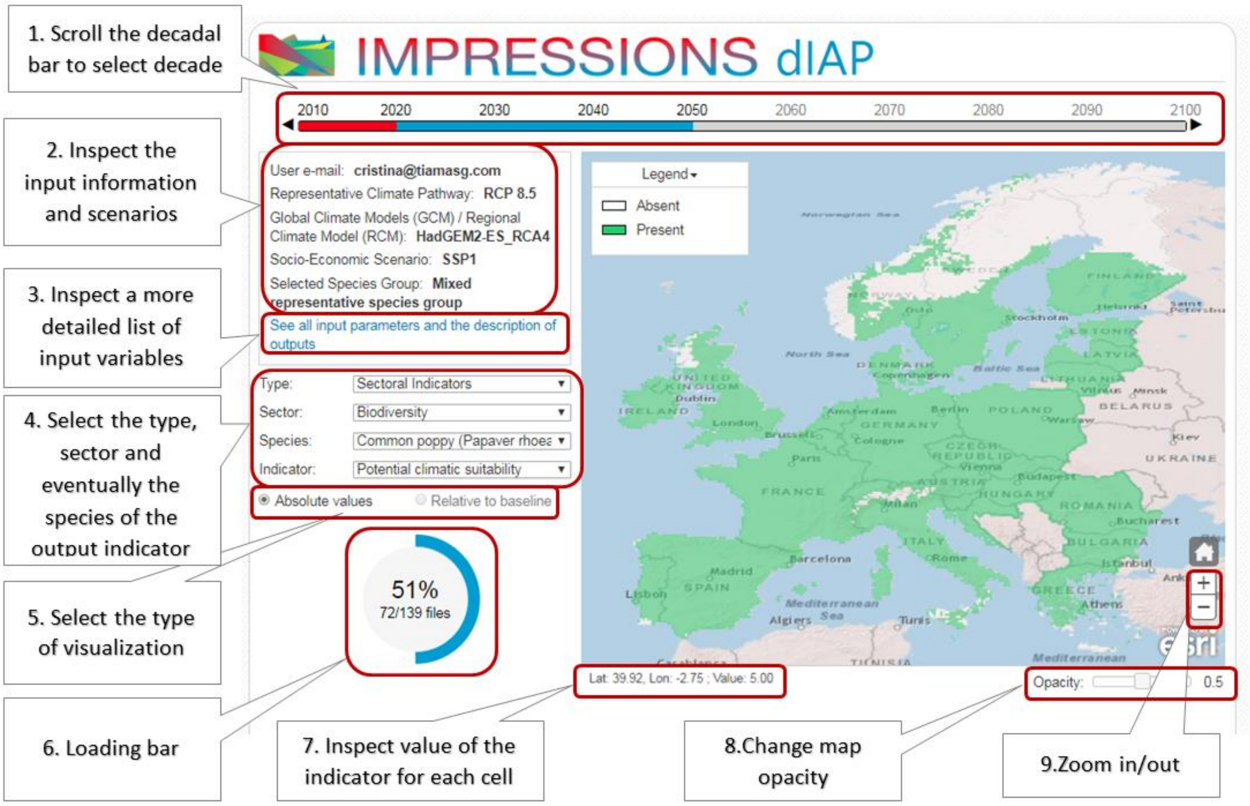


Figure 4.11 IMPRESSIONS dIAP - User Output Module – Map visualization

Figure 4.12 IMPRESSIONS dIAP - User Output Module – “Set Legend” options

***Tipping Points*:**

- A possible tipping point situation was identified as depicted in *Figure 4.13* for People flooded.

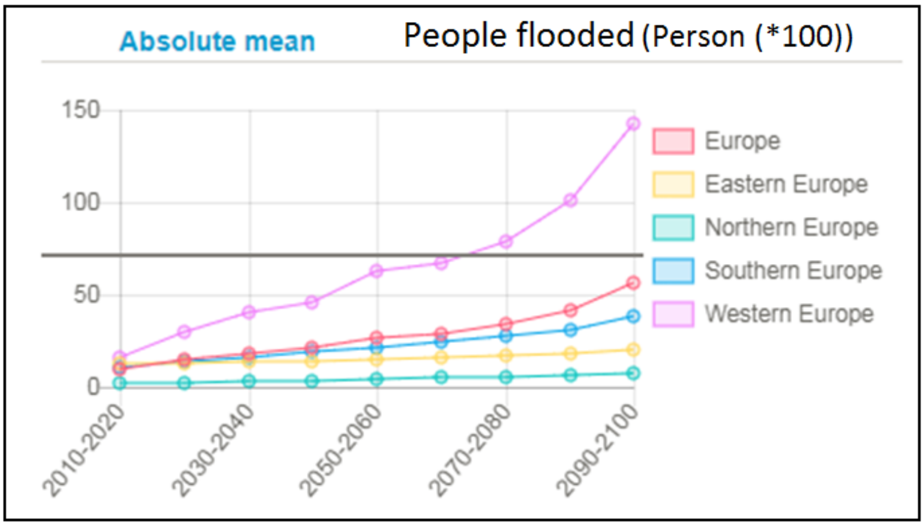


Figure 4.13 IMPRESSIONS dIAP - User Output Module – Tipping points example

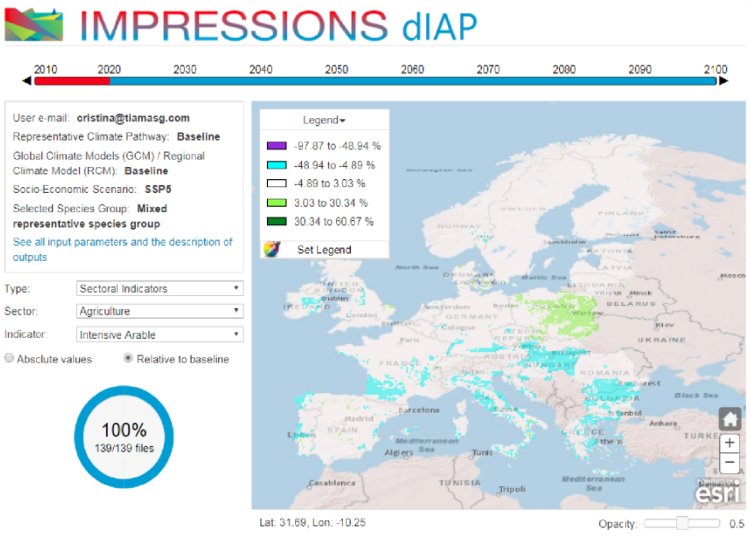
Tables and graphic statistics

In the lower part of the Output Interface (*Figure 4.14*) graphics and tables corresponding to the selected indicator are depicted. The statistics that are calculated are depicted for whole Europe and for regions in Europe (Eastern, Northern, Southern and Western). Each country belongs to only one region. In terms of the statistics that are calculated:

- The mean is calculated at cell level for each region.
- Standard deviation is also calculated at cell level.
- The mean relative to baseline is calculated as the difference mean between the current results and the ones at baseline.
- The standard deviation relative to baseline is computed relative to the mean statistics calculated previously.

The graphics depict both absolute and relative statistics for all nine decades and for all regions.

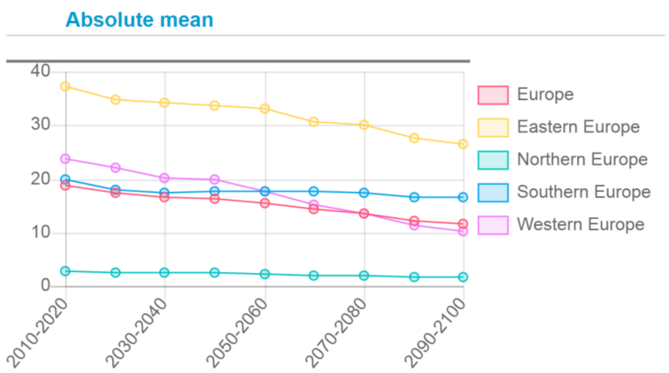
As a conclusion, IMPRESSIONS dIAP aims to simulate the effects of high-end scenarios that have been defined in a participatory manner with the help of stakeholders. IMPRESSIONS dIAP also aims to draw attention over the potential devastating effects that climate change can have on a wide range of sectors (urban, hydrological, forest, coastal, agricultural, biodiversity). Enabling possible ways of adapting, dIAP can be viewed as a platform with potential wide usage that can lead to an improved quality of life and environment.



Statistics (cell level) - Intensive Arable (%)

Europe | Eastern Europe | Northern Europe | Southern Europe | Western Europe

Decade	Absolute values			Relative values to baseline	
	Mean	Standard deviation	Number of cells	Mean	Standard deviation
2010-2020	18.7526	23.4290	24131	-6.57%	-4.80%
2020-2030	17.2507	22.9809	24131	-14.05%	-6.62%
2030-2040	16.4679	23.1291	24131	-17.95%	-6.02%
2040-2050	16.3456	23.8148	24131	-18.56%	-3.23%
2050-2060	15.5354	23.7062	24131	-22.60%	-3.68%
2060-2070	14.2965	23.1762	24131	-28.77%	-5.83%
2070-2080	13.6218	22.9860	24131	-32.13%	-6.60%
2080-2090	12.2634	22.0400	24131	-38.90%	-10.45%
2090-2100	11.6777	21.7537	24131	-41.82%	-11.61%



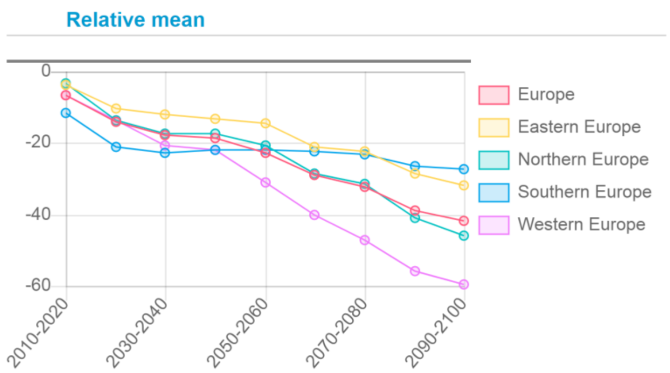


Figure 4.14 IMPRESSIONS dIAP - User Output Module – Tables and graphic statistics section

4.5.4 Meta-model components

Similar to CLIMSAVE, in order to improve IMPRESSIONS dIAP development and maintenance processes, all integrated meta-models were designed as independent software components, and possible to be replaced with an improved version at any time. Thus, it was necessary to develop clear specifications to enable integration and communication between meta-models. These specifications are independent from the algorithms implemented in each meta-model.

For a fruitful integration and interconnection, a series of patterns and protocols were agreed and developed. They are similar to the ones applied in CLIMSAVE IAP. These steps are briefly mentioned below, underlining, where necessary, the differences or improvements to CLIMSAVE IAP:

1. Defining data spatial resolution at which information is transferred between meta-models – the 10'x10' (16kmx16km) resolution was maintained. However, the number of cells is 24131 for the whole Europe, greater than the one in CLIMSAVE IAP (23181) due to the addition of Malta and Croatia to the countries where climate change impacts can be simulated.
2. Meta-model input and output identification - some meta-models from CLIMSAVE IAP have been changed, some have been added and some have disappeared. The list of the interconnected meta-models for IMPRESSIONS dIAP and whether they are new or changed is the following:
    a. RUG – Urban Model - new model
    b. WGMM – Water Models - updated meta-model
    c. CFFlood – Flood Model - updated meta-model
    d. Crop – Crop model - new meta-model
    e. ForCLIM – Forest model - new meta-model
    f. SFARMOD – Agricultural model - updated meta-model
    g. SPECIES – Biodiversity model - updated meta-model
3. Identifying links between meta-models, which within the platform are represented as data transfers between the targets. For example, artificial surface and the extent of urban development calculated in the Urban module influence the population at risk of flooding (CFFlood meta-model), hydrological basins (WGMM meta-model), agricultural area available (SFARMOD meta-model) and ultimately habitat availability (SPECIES meta-model).
4. Completing data dictionaries through which each meta-model’s type, links and connections are specified. The need of development of these data dictionaries was due to the need of different types of data transfer:
    a. Transferring input data supplied by the user in the graphical interface to the meta-models – feature provided by User Input Interface and Control Module
    b. Transferring data from a meta-model to another - results from one meta-model are inputs to another

c. Transferring output data from the meta-model to the user - achieved through User Output Module
d. Transferring data from the database (in the socio-economic and climatic scenarios) to the meta-models
e. Transferring data within the same meta-model from one decade to another
f. Transferring data from internal files to the meta-models

All types of transfer mentioned above, except the last one, were specified and detailed in the data dictionaries. Thus, for each variable the following were mentioned (similar to CLIMSAVE IAP):

a. If the variable is an input or an output
b. If it is an input its source should be specified (User Input Module, dIAP database, another meta-model or meta-model output from previous step - in this case the variable should be preceded by a "pre_" header)
c. The variable name as used in meta-model code
d. The whole variable explicit definition
e. Type - Single, Integer, Float
f. Measurement Unit - meters, hectares etc.
g. If the variable is an output it should be specified whether it is used in another meta-model or if it is displayed to the user. If the meta-model reuses this variable the name of the variable should be preceded by the "cur_" header.

5. Data dictionaries standardization - *Figure 4.15* depicts part of a data dictionary.

As noted above, meta-models were implemented as DLLs, therefore, various programming languages were used such as Microsoft C++, the Microsoft C #, Microsoft VB, Delphi, etc. They were interconnected with the Control Module and work as a whole. The Control Module provides the necessary data to the DLLs, it runs them in a predetermined order, gather data outputs and stores them. At the end of a scenario execution, the Control Module sends an e-mail to the user with a web address where the results can be viewed.

All these models interact with each other, the output indicators of some of them are inputs for the others. The interaction scheme between models is depicted in *Figure 4.16*. Similar to CLIMSAVE, the reason for which *Figure 4.16* depicts 9 sub-processes and not 7 (the number of meta-models integrated in IMPRESSIONS dIAP), is that the Water meta-model runs 3 times in different places of a simulation process, due to its sub-models (Hydrology, Water availability and Water Use).

Row nr	Variable/parameter name	Definition of variable/parameter	What is the source of the input?	Unit	Spatial resolution	Temporal resolution
1	inpWGMMHstruct.DeltaP	Long-term avarage annual precipitation (absolute value)	dIAP (scenario input)	mm	Regular grid (10')	decadal
2	inpWGMMHstruct.DeltaT	Long-term annual mean air temperature (absolute value)	dIAP (scenario input)	°C	Regular grid (10')	decadal
3	inpWGMMU1struct.RUG_CELL_PopCount_Total_Baseline	total population per in grid cell in the baseline (eg 2010)	dIAP Central DB	1000 people	Regular grid (10')	decadal
4	inpWGMMU1struct.RUG_CELL_PopCount_Total_Decade	total population per in grid cell in the decade the model is run for (eg 2080s)	RUG	1000 people	Regular grid (10')	decadal
5	inpWGMMU1struct.RUG_Non_Residential_Baseline	percentage of land area in grid cell covered by non-residential artificial surface in the baseline (eg 2010)	dIAP Central DB	% of cell land area	Regular grid (10')	decadal
6	inpWGMMU1struct.RUG_Non_Residential_Decade	percentage of land area in grid cell covered by non-residential artificial surface in the decade the model is run for (eg 2080s)	RUG	% of cell land area	Regular grid (10')	decadal
7	inpWGMMU1struct.GridCellLandArea	land area of grid cell used together with percentage of non residential area for downscaling of manufacturing water use (actual unit is meaningless).	dIAP Central DB	ha	Regular grid (10')	static information

Figure 4.15 IMPRESSIONS dIAP WGMM meta-model data dictionary section

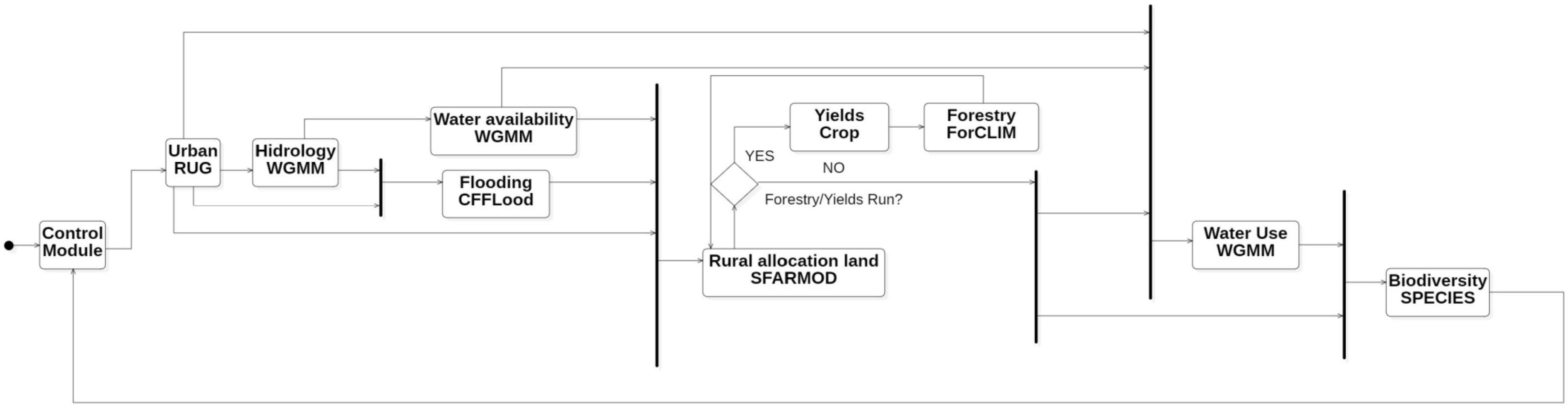


Figure 4.16 IMPRESSIONS dIAP meta-models execution flow (UML activity diagram)

4.5.4.1 IMPRESSIONS meta-models

Below are described the meta-models that were included in the IMPRESSIONS dIAP. Many of them are upgraded versions of existing CLIMSAVE IAP (WGMM, CFFlood, SFARMOD, SPECIES), others are new models that replace some of the old meta-models (RUG, ForCLIM, Crop). For models that have undergone improvements, these are further highlighted.

The description of the urban meta-model is more detailed, given my involvement in the development of this model.

4.5.4.1.1 RUG

According to the data provided by Eurostat Yearbook [**13**], Europe's urban and suburban artificial areas account for 4% of Europe's total surface area and are home to more than 72% of the continent's total population [**28**]. They are responsible for about 70% of the carbon dioxide emitted at European level [**12**]. Thus, artificial urban areas are often responsible for reducing biodiversity and the good functioning of ecosystems by dynamic and unorganized spreading having as main purpose to meet the needs of people and society. Important factors that influence the future development of urban areas are:

- Changes in social and environmental urban policies
- Population structure change
- Changes in population social and cultural preferences
- Restriction or development policies for certain areas

Urban development directives directly influence European climate and environmental changes. The trend to migrate towards expanded urban areas with a lower density rather than large cities [**11**] is one of the factors that can determine this.

The urban model simulates urban development trends in order to integrate them into IMPRESSIONS dIAP. However, it can be used separately from within the platform. Output indicators that ultimately reflect these trends are the size of artificial surfaces and the change in demographic structure. The main facilities considered for the model were:

- inter-connection with other existing sectors within the platform: as input data RUG receives data on European protected areas from PA module and population data from the database. As output data RUG provides data on artificial surfaces and population to WGMM, CFFlood and SFARMOD meta-models.
- the possibility of customizing the model by providing input indicators that can be modified to simulate various scenarios
- the decadal run in which the model takes into account the urban results obtained in the previous period
- dynamics

- obtaining the results at the resolution required by the platform (10'x10') given that some of the data on which the model is based are provided at NUTS2 (Nomenclature of Territorial Units for Statistics) level (Population density, Population change).

The two resolutions used by the model (NUTS2 and 10'x10' platform resolution) are also due to the demographic and artificial surface data existing at NUTS2 level. Thus, calculations on the expansion of urban areas are made at NUTS2 level and then distributed and applied to dIAP platform's resolution.

4.5.4.1.1.1 Model characteristics

The term artificial surface is general. The RUG model is based on CORINE (Coordination of Information on the Environment) land cover [**7**] which provides information on a range of data specific to various sectors, including the urban one. CORINE classifies artificial surfaces in residential areas represented by urban areas and non-residential areas consisting mostly of industrial areas. Going forward Eurostat [**58**] classifies residential areas in:

- Cities (densely populated areas) – in RUG they are referred as R1
- Towns and suburbs (intermediate density areas) - in RUG they are referred as R2
- Rural areas (thinly populated areas) - in RUG they are referred as R3

RUG takes this classification into account and uses it in the urban and population computing algorithm.

From the population point of view and its development within RUG, an age classification is considered:

- [0,14] years
- [15,29] years
- [30,49] years
- [50,64] years
- [65,74] years
- > 75 years

4.5.4.1.1.2 Preference Matrix

This classification is useful at the time of integrating population's preferences for urban development, different classes having different preferences. For example, cities with a lower density are preferred by retirees and families with children, while densely populated cities are preferred by young people and families without children [**28**]. To this end, it is important to define and quantify the preferences of different age types for different residential types.

The quantification took into account that the first age group ([0-14] years) represents the children, and they can be assimilated into the age groups of their parents, namely [15,29] and [30,49] years. The last two categories ([65, 74] years and > 75 years) were also merged given that they have similar residential preferences. RUG model calculates a preference matrix based on:

- Eurostat data [**14**] on the density of urban areas
- population by age groups
- living standards within the RUG model

However, population's preference to a particular residential sector can also be modified from the user interface of IMPRESSIONS dIAP through 5 indicators:

- Sprawl R1 (dense) to R2 (intermediate) - Modifier of preference matrix to reflect scenario. Shifts population preference from residential type R1 (dense) to residential type R2 (intermediate). Value represents the proportional shift in preference, for example, a value of zero indicates no change, whereas a value of one indicates a complete shift in preference between types.
- Sprawl R2 (intermediate) to R3 (rural) - Modifier of preference matrix to reflect scenario. Shifts population preference from residential type R2 (intermediate) to residential type R3 (rural). Value represents the proportional shift in preference as mentioned above.
- Compact R3 (rural) to R2 (intermediate) - Modifier of preference matrix to reflect scenario. Shifts population preference from residential type R3 (rural) to residential type R2 (intermediate). Value represents the proportional shift in preference as described above.
- Compact R2 (intermediate) to R1 (dense) - Modifier of preference matrix to reflect scenario. Shifts population preference from residential type R2 (intermediate) to residential type R1 (dense). Value represents the proportional shift in preference as mentioned above.
- Preferences for Compact vs Sprawl - Variables describing societal preferences for compact (sustainable) versus sprawling cities.

The preferences modified by these parameters are applied to all age groups.

4.5.4.1.1.3 Artificial surface demand

The decadal increase in artificial surfaces is calculated on the basis of:

- Population at NUTS2 level for each type of residence calculated by RUG based on:
    - the demographic change defined in the socio-economic scenario at NUTS2 level (obtained a priori by dividing the national data obtained from the International Institute for Applied Systems Analysis (IIASA) databases)
    - distribution of population by age group at NUTS2 level (calculated using the preference matrix)
- Population density for each type at NUTS2 level
- Input indicator: Planning Control R1/R2

- Existing artificial surface from the last decade

The calculation of the residential area growth is computed for each type of residence.

The increase in non-residential surface is based on the increase in residential artificial surfaces and on the non-residential area coming from the previous decade.

4.5.4.1.1.4 Splitting artificial surface growth at cell level

The allocation of artificial surface growth at cell level is made in accordance with the cell-specific transition potential and taking into account the existing NUTS2 level restrictions. The transition potential depends on:

- the way in which types of residence can influence each other
- population preference for relocation:
    - interest in green areas rather than urban agglomerations. The correspondent input indicator from the User Input Module is:
        - Household externalities preference - Preference as to whether population prefer green spaces (5) versus urban areas (1)
    - attractiveness to coastal areas, near protected areas or near lakes and rivers. In the User Input Module there are three correspondent input indicators:
        - Attractiveness of coast - Preference as to whether population prefers to live at coast. A value of 1 indicates coasts are highly attractive, whereas 0 indicates they are not influencing societal location preferences.
        - Attractiveness of natural features - Preference as to whether population prefers to live near natural features (Protected Areas). Value represents the protected areas attractiveness as described above.
        - Attractiveness of coast inland water - Preference as to whether population refers to live near inland water features (rivers and lakes). Value represents the attractiveness of inland waterbodies as described above.

The probability of artificial surfaces to interact with each other is modeled in RUG in the form of a transition matrix and is calculated according to the artificial surfaces diffusion for baseline. All types of artificial surfaces including non-residential surfaces are considered within this matrix. Values are calculated taking into account the percentage of artificial surfaces in the immediate vicinity of the grid cell for which the matrix is calculated. Thus, a grid cell located in the immediate vicinity of a city is more likely to become a residential area in the future.

The population relocation in different areas depends on the current residence and on the motives, whether social or environmental, which cause them to relocate. For example, those living in dense residential areas tend to access green areas near them. With regard to the attractiveness of different natural areas, Eurostat [**13**] data show that the population aged over 65 is predisposed to relocate to areas located on the coast.

As mentioned before, to distribute the NUTS2 artificial surface required at cell level the transition potential is needed. This factor is different depending on the location, scenario and type of residence. As a limitation, artificial surfaces cannot develop in areas with large slopes, protected areas or in zones located in the immediate vicinity of water. Also, urban development starts from an existing urban settlement. If these conditions cannot be met for cells within a NUTS2 unit, it means that the population cannot be relocated. RUG model does not take into consideration the idea of transferring the population to another NUTS2 region.

The population distribution from NUTS2 level to grid cell level is proportional to the percentage of artificial surfaces located in the specific NUTS2 region and admitting that the population for each type of residence has the same density.

In terms of implementation, RUG contains 4 internal modules detailed in Annex 4.

To conclude, RUG model simulates the change that is probable to occur in European artificial surfaces considering GDP per capita, population and the urban residential and non-residential areas. Other important factors in simulating artificial surfaces are the propensity to live in coastal areas, population preference for living in rural or urban areas and also the development of spatial planning.

4.5.4.1.2 WGMM

WGMM meta-model is built with the help of a more complex model - WaterGAP [**1**] which assesses the changes occurring on water consumption and resources due to climate change. The water meta-model comprises two sub-models which do not re-use their parameters from one decade to another and the algorithms within the hydrological and water use sub-models depend on the climatic inputs (rainfall and temperatures) and some of them come from SFARMOD meta-model. The 10-year period is long enough for the average of these values to characterize a stable state to be provided to the sub-models. Therefore, the meta-model has changed insignificantly compared to the CLIMSAVE IAP version by adding and removing some input and output indicators.

4.5.4.1.3 CFFlood

Flood sector - CFFlood meta-model [**27**] - simulates the impacts of climate and socio-economic scenarios on floodplains in Europe. The meta-model assesses possible flooding in coastal areas, river basins and floodplain. The CFFlood meta-model has been upgraded from its version from CLIMSAVE IAP. In IMPRESSIONS it simulates the impact of coastal floods, the impact of floods on the river level and the evolution of maze surfaces. In terms of input data, the internal databases have been modified to meet the new IMPRESSIONS requirements (e.g.: 2010 baseline for the land use database). The new version of the meta-model allows simulation of impacts and the determination of vulnerabilities at decadal level up to 2100. Meta-model calibrations were undertaken to meet this matter. Thus, the meta-model is based on the needed baseline data and on the changes estimated by 2100 that will occur for these data. The CLIMSAVE IAP meta-model interactions with other modules remain the same: CFFlood receives data from WGMM and RUG.

4.5.4.1.4 ForCLIM

ForCLIM, like RUG, is a new forest model within IMPRESSIONS dIAP. The model is dynamic and evaluates the evolution of various types of forests in temperate Europe. ForCLIM model simulates the sequence of tree species in Central Europe and Europe's temperate regions [**6**] considering their growth rate, level of propagation and mortality in the given climatic conditions. The model receives as inputs climatic data for the current time period, future climatic data, soil data, but also data regarding the forest species and their condition calculated for the previous decade by the same model. The main output indicators include timber production, existing forest species, the amount of carbon stored in them, and the forest areas. These output variables are forwarded to the SFARMOD module, from which they are then taken over by the Control Module.

4.5.4.1.5 Crop

Crop meta-model, similar to RUG and ForCLIM, is a new meta-model developed based on a predictive model of long term cultures (Yield-SAFE - Yield Estimator for Long term Design of Silvoarable Agroforestry in Europe [**53**]) that uses equations to simulate crop growth and effective production. These equations take into consideration cropping patterns and the dates on which they were planted, average temperatures, radiation and rainfall. The meta-model calculates yields per territorial unit and the extent to which they change over the course of 10 years. Some of the crops simulated by the meta-model are: Soya, Sunflower, Maize, Wheat, Winter/Spring Barley, Potatoes, Winter/Spring Beans. The meta-model output indicators are passed to SFARMOD from where they are sent to the Control Module of the platform.

4.5.4.1.6 SFARMOD

SFARMOD meta-model [**3**] - allocates rural areas based on the demand and profitability of the agricultural and forest sector (otherwise areas remain unused). The decision of these allocations is based on medium and long term assessments of their profitability, and taking into account soil type, crop potential and level of precipitation. SFARMOD is not a new meta-model, but it improves the one from CLIMSAVE IAP. Changes have been made to allow the integration of Crop and ForCLIM output variables. SFARMOD uses the indicators received from these two modules to integrate and alter them according to the results of the internal algorithm and forward them to the Control Module. Thus, land use can be: intensive or extensive farming, grazing, managed and unmanaged forest and abandoned. Compared to CLIMSAVE IAP, the way in which one type of soil usage shifts to another was improved by financial estimates but also by taking into account the high-risk crops or the minimum period that is required to shift from one type of soil usage to another.

4.5.4.1.7 SPECIES

SPECIES meta-model [**33**] - simulates the way climate change impacts over 111 species in Europe. Similar to CLIMSAVE, this meta-model interacts with almost all sectors mentioned above: urban, water, flood, agriculture and forestry. The meta-model identifies possible habitats of various species depending on soil type, climate data such as rainfall, temperatures and wind. Existing habitats and protected areas are also considered and are taken from Natura 2000 [**30**]. Compared to the Biodiversity module from CLIMSAVE, the one from IMPRESSIONS has been improved and aims at simulating the distribution of species at European level. In the new version, the presence/absence of species in a particular region determined by climatic and habitat conditions in a decade influences the results of the next decade. Thus, the region may remain stable, lose or gain habitat suitability for a series of species. For every cell in IMPRESSIONS dIAP, a stress indicator is calculated to determine the species extinction within that area. The improved version also includes a new feature taking into account the possibility of species dispersion from one region to another. This is useful for cells where all or a lot of species have been lost.

4.6 Results

IMPRESSIONS dIAP enables simulation, understanding and visualization of both current situation and probable future high-end scenarios, encouraging exploration of measures that can be taken to adapt or prevent unwanted phenomena. The novelty of IMPRESSIONS dIAP consists, besides its interactivity, broad accessibility, online availability and flexibility, in the integration into one platform of different sectorial meta-models, identifying closely the linkages between them and making possible to run them as a whole, its results confirming current reality and anticipating future possible scenario effects. IMPRESSIONS dIAP provides a wide range of future climatic and socio-economic scenarios which can be selected either individually or in various combinations.

The following paragraphs present important meta-model results depicting customized scenarios. The customization was as follows:

1. increase in winter and summer precipitations by 10% for each decade, CO_2 set to 300 ppm and SSP1 socio-economic scenario
2. increase in mean annual temperature by 2° Celsius for each decade, CO_2 level set to 400 ppm and SSP5 socio-economic scenario

RUG – The urban module is not influenced directly by any of the climatic changes, but socio-economic scenarios play an important role in the development of artificial surfaces as well as in the evolution of population. The artificial surface output indicator from RUG supports the descriptions of both SSP scenarios that are taken into consideration: SSP1 and SSP5. *Figure 4.17* and *Figure 4.18* present the statistics from 2010 until 2100 for artificial surfaces for the two scenario sets. The small increase in artificial surfaces for the first scenario combination can be explained by the population decrease which according to SSP1 description is a characteristic of this SSP. The artificial surfaces increase shown in *Figure 4.18* is consistent with SSP5 storyline which describes a population increase. However, this increase in both artificial surfaces and population can be mostly seen near big cities.

SFARMOD – Intensive arable output indicator was chosen to represent best the behavior of SFARMOD under the two above scenario combinations. *Figure 4.19* and *Figure 4.20* depict the results of the two scenario combinations for 2010-2020:

1. Intensive arable increases in the first proposed scenario probably due to the increase in precipitations. An increase of 4 to 41% relative to the baseline intensive arable land is present almost in all Europe.
2. Intensive arable decreases in the second proposed scenario due to temperature and CO_2 raise. A decrease of 5 to 49% relative to the baseline intensive arable land is present almost in all Southern and Eastern European regions.

Figure 4.21 and *Figure 4.22* present the statistics of intensive arable indicator until 2100 and the increase of this indicator continues for the first scenario until the last decade. A similar behavior is reported in the second scenario combination with the difference that in this case the decrease of the indicator is continuous until 2100.

WGMM - Under the same scenario combinations water availability (output within the WGMM meta-model) is:

1. increasing in the first scenario combination, the biggest recorded values are in Northern and Central Europe – *Figure 4.23*. These increased results are consistent with the increased winter and summer precipitation correspondent to the selected scenario.
2. decreasing in the second scenario combination. Following *Figure 4.24*, a decrease in water availability is recorded in most European regions. Due to the location of the river basins, the most affected areas are Northern and Central Europe. The decrease of water availability output is due to the increase in mean annual temperature specific to the second scenario.

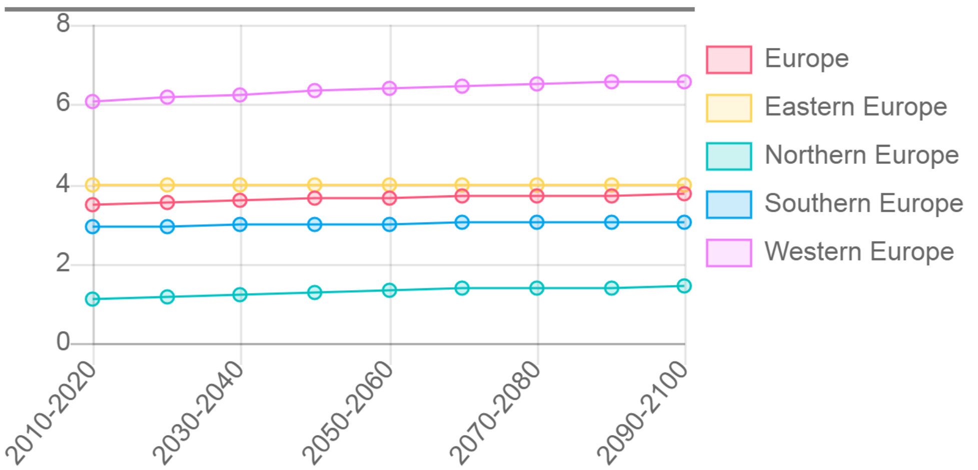
The above results highlight the possibility of exploring user customized scenarios. Similar to CLIMSAVE IAP, these results confirm and validate not only the meta-models but also the scenarios integrated into IMPRESSIONS dIAP.

Statistics (cell level) - Artificial surfaces (%)

Europe | Eastern Europe | Northern Europe | Southern Europe | Western Europe

Decade	Absolute values			Relative values to baseline	
	Mean	Standard deviation	Number of cells	Mean	Standard deviation
2010-2020	3.4578	6.2958	24131	+2.99%	+2.23%
2020-2030	3.5146	6.3661	24131	+4.68%	+3.38%
2030-2040	3.5650	6.4355	24131	+6.19%	+4.50%
2040-2050	3.6158	6.5069	24131	+7.70%	+5.66%
2050-2060	3.6541	6.5669	24131	+8.84%	+6.64%
2060-2070	3.6876	6.6169	24131	+9.84%	+7.45%
2070-2080	3.7089	6.6489	24131	+10.47%	+7.97%
2080-2090	3.7200	6.6632	24131	+10.80%	+8.20%
2090-2100	3.7320	6.6782	24131	+11.16%	+8.44%

Absolute mean



Relative mean

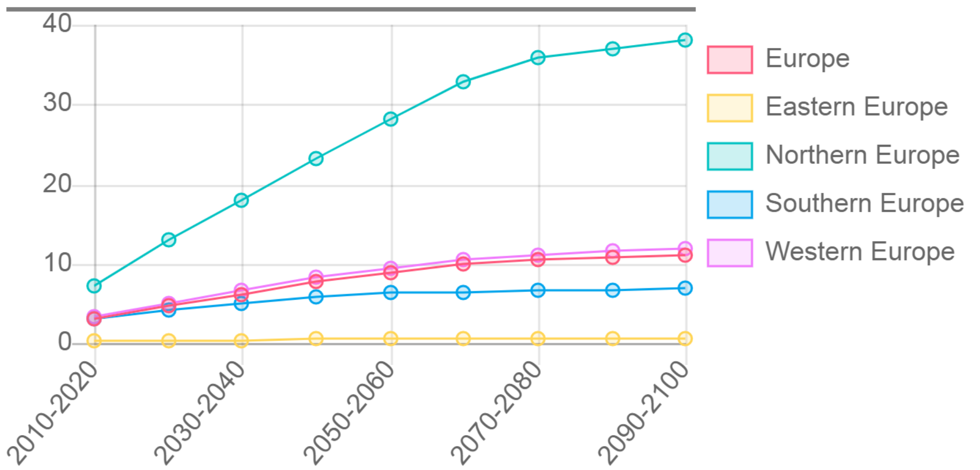


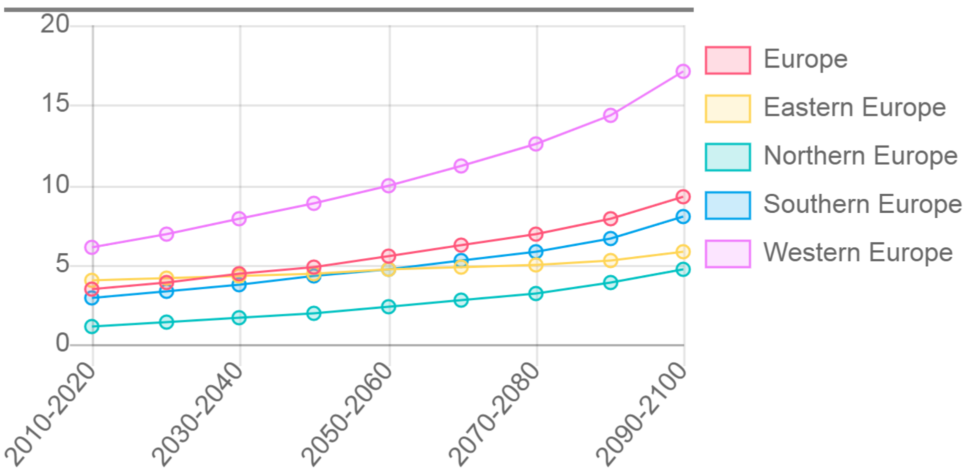
Figure 4.17 RUG: 2010 – 2100 statistics for artificial surfaces for SSP1

Statistics (cell level) - Artificial surfaces (%)

Europe | Eastern Europe | Northern Europe | Southern Europe | Western Europe

Decade	Absolute values			Relative values to baseline	
	Mean	Standard deviation	Number of cells	Mean	Standard deviation
2010-2020	3.4940	6.3796	24131	+4.07%	+3.60%
2020-2030	3.9176	7.2241	24131	+16.69%	+17.31%
2030-2040	4.3696	8.2157	24131	+30.15%	+33.41%
2040-2050	4.8942	9.2980	24131	+45.78%	+50.99%
2050-2060	5.5000	10.5180	24131	+63.82%	+70.80%
2060-2070	6.1452	11.7274	24131	+83.04%	+90.44%
2070-2080	6.8491	12.9282	24131	+104.01%	+109.94%
2080-2090	7.8013	14.5286	24131	+132.37%	+135.92%
2090-2100	9.2170	16.7399	24131	+174.54%	+171.83%

Absolute mean



Relative mean

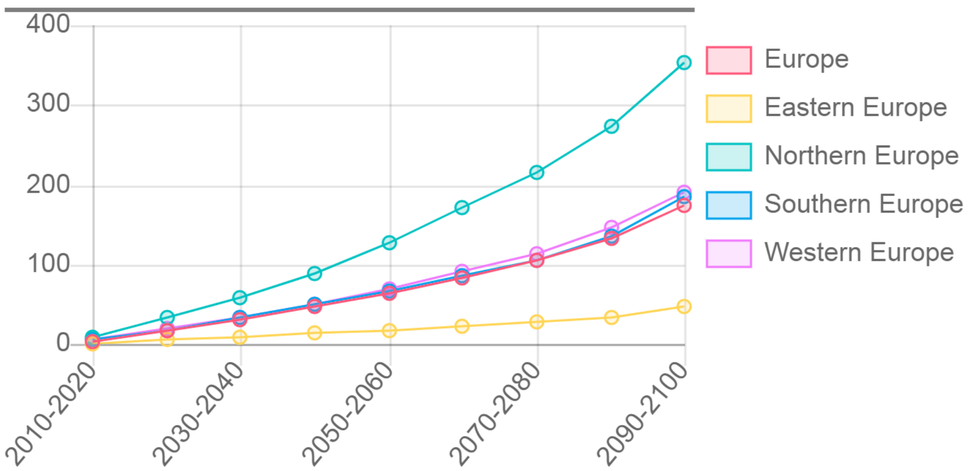


Figure 4.18 RUG: 2010 – 2100 statistics for artificial surfaces for SSP5

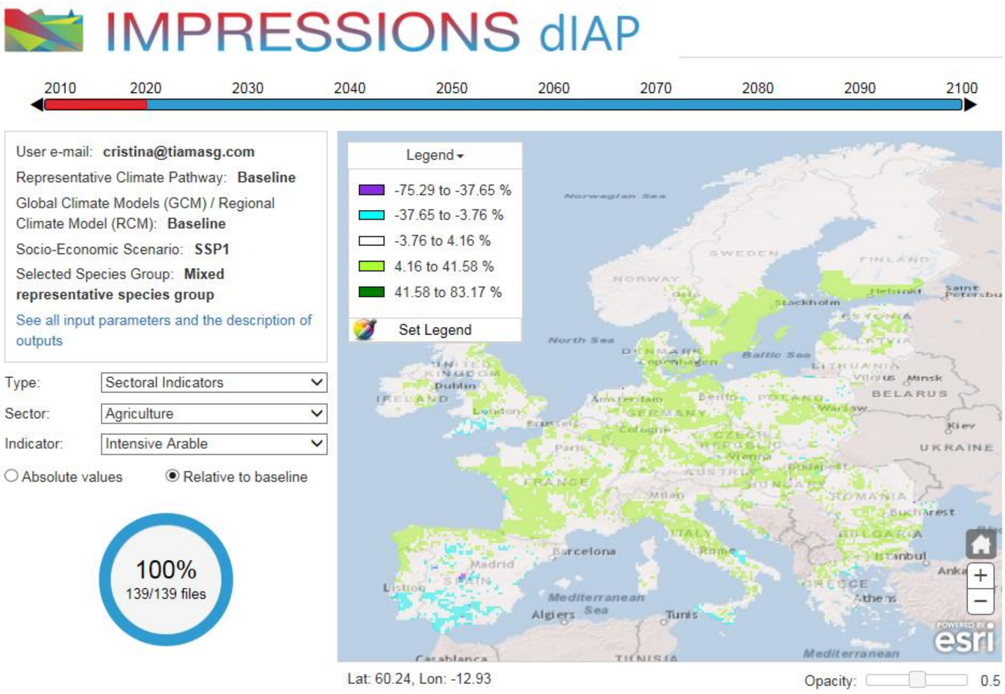


Figure 4.19 SFARMOD: 2010-2020: Intensive arable for increase in winter and summer precipitations by 10%, CO_2 set to 300 and SSP1 (relative to baseline values)

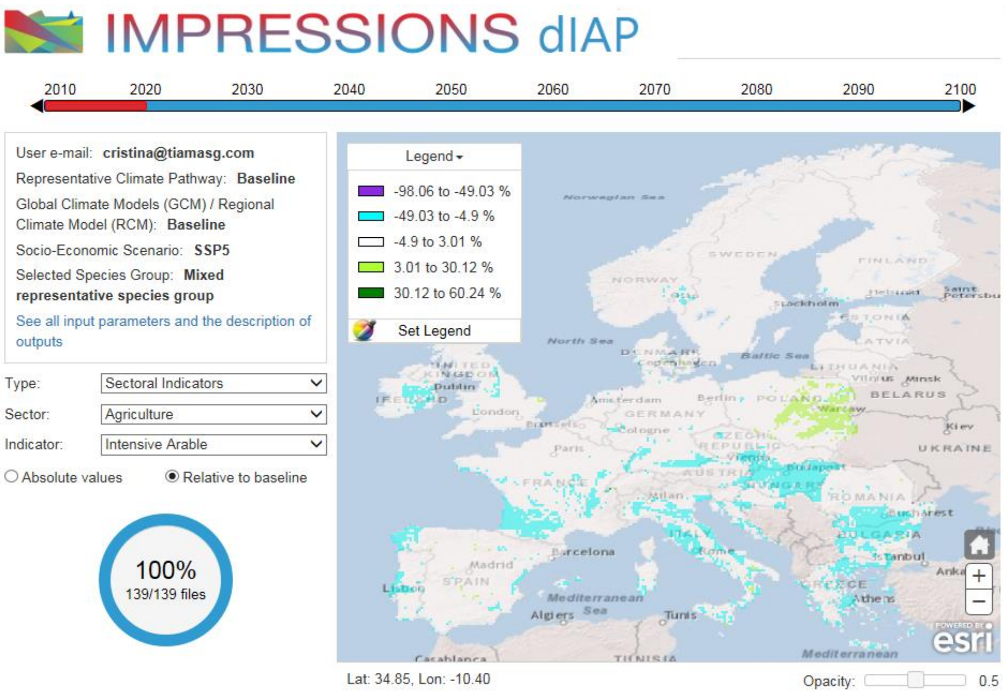


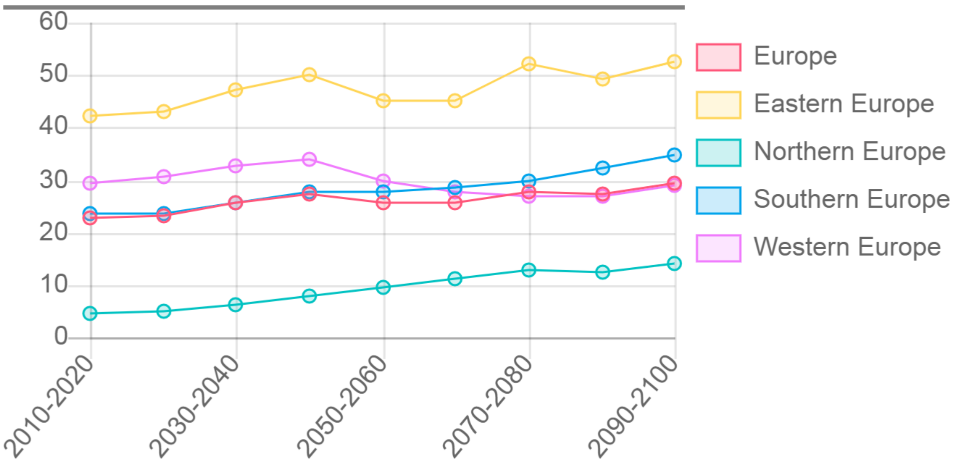
Figure 4.20 SFARMOD: 2010-2020: Intensive arable for increase in mean annual temperature by 2°C, CO_2 level set to 400 ppm and SSP5 (relative to baseline values)

Statistics (cell level) - Intensive Arable (%)

Europe | Eastern Europe | Northern Europe | Southern Europe | Western Europe

Decade	Absolute values			Relative values to baseline	
	Mean	Standard deviation	Number of cells	Mean	Standard deviation
2010-2020	22.6533	25.9621	24131	+12.86%	+5.49%
2020-2030	23.1822	26.5703	24131	+15.50%	+7.96%
2030-2040	25.5078	28.0822	24131	+27.08%	+14.11%
2040-2050	27.3715	29.1773	24131	+36.37%	+18.56%
2050-2060	25.6840	27.9839	24131	+27.96%	+13.71%
2060-2070	25.7787	28.5151	24131	+28.43%	+15.87%
2070-2080	27.7078	29.4119	24131	+38.04%	+19.51%
2080-2090	27.4960	28.7935	24131	+36.99%	+17.00%
2090-2100	29.5642	30.2264	24131	+47.29%	+22.82%

Absolute mean



Relative mean

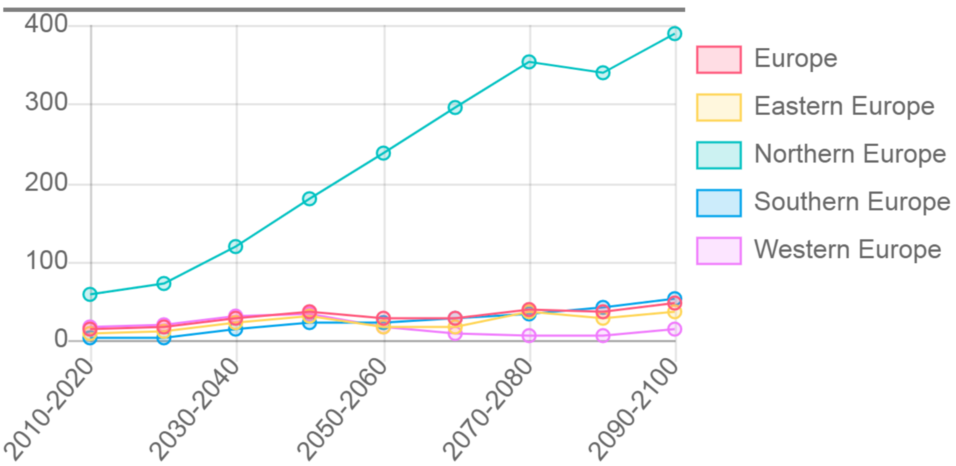


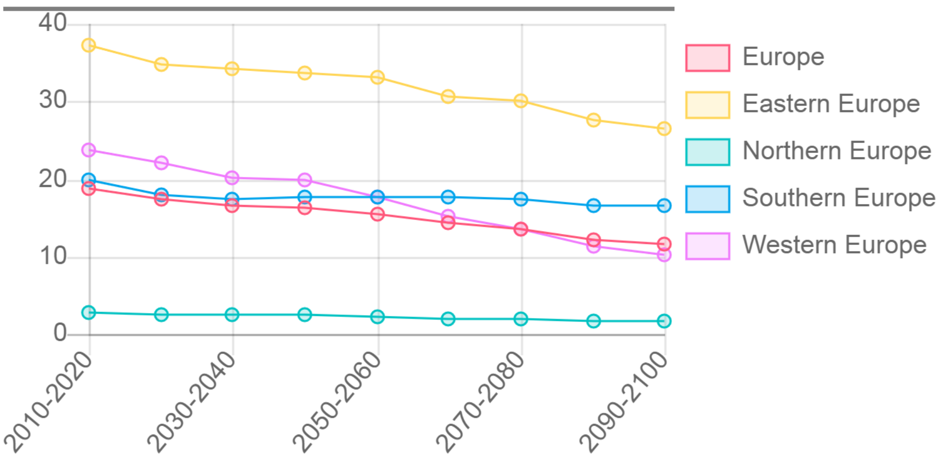
Figure 4.21 SFARMOD: 2010 – 2100 statistics for intensive arable for increase in winter and summer precipitations by 10%, CO_2 set to 300 and SSP1

Statistics (cell level) - Intensive Arable (%)

Europe | Eastern Europe | Northern Europe | Southern Europe | Western Europe

Decade	Absolute values			Relative values to baseline	
	Mean	Standard deviation	Number of cells	Mean	Standard deviation
2010-2020	18.7526	23.4290	24131	-6.57%	-4.80%
2020-2030	17.2507	22.9809	24131	-14.05%	-6.62%
2030-2040	16.4679	23.1291	24131	-17.95%	-6.02%
2040-2050	16.3456	23.8148	24131	-18.56%	-3.23%
2050-2060	15.5354	23.7062	24131	-22.60%	-3.68%
2060-2070	14.2965	23.1762	24131	-28.77%	-5.83%
2070-2080	13.6218	22.9860	24131	-32.13%	-6.60%
2080-2090	12.2634	22.0400	24131	-38.90%	-10.45%
2090-2100	11.6777	21.7537	24131	-41.82%	-11.61%

Absolute mean



Relative mean

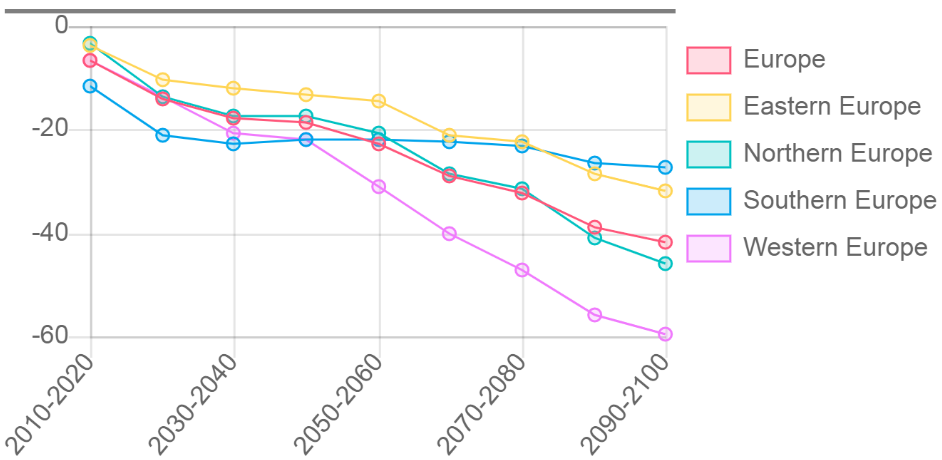


Figure 4.22 SFARMOD: 2010 – 2100 statistics for intensive arable for increase in mean annual temperature by 2°C, CO_2 level set to 400 ppm and SSP5

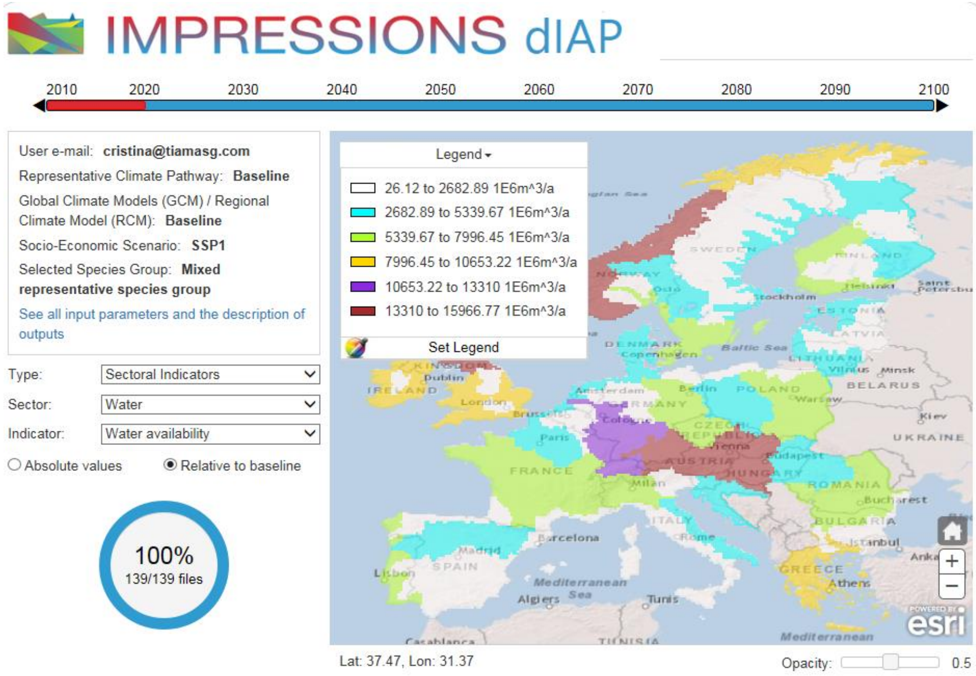


Figure 4.23 WGMM: 2010-2020: Water availability for increase in winter and summer precipitations by 10%, CO2 set to 300 and SSP1 (relative to baseline values)

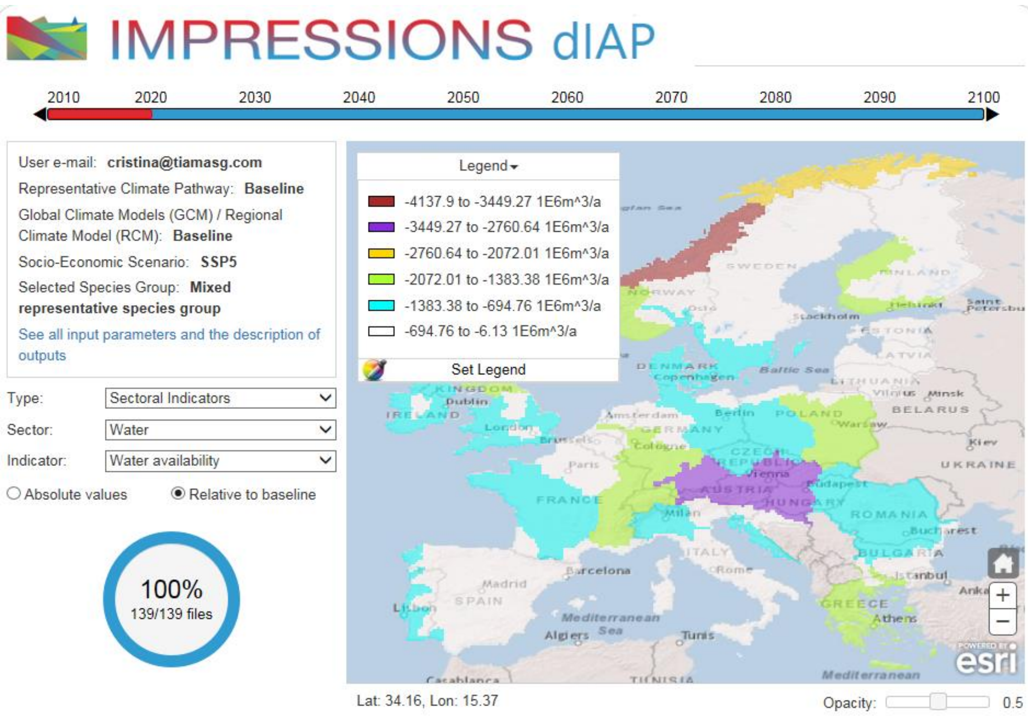


Figure 4.24 WGMM: 2010-2020: Water availability for increase in mean annual temperature by 2°C, CO_2 level set to 400 ppm and SSP5 (relative to baseline values)

5 CONCLUSIONS AND FUTURE WORK

Climate changes are part of nowadays reality by current temperature growth, changes in existing weather patterns but also by many increasing extreme events that we face more and more often. In these circumstances there is a need to raise awareness on the harmful effects that these changes may have on our wellbeing.

Thus, in the context of climate change affecting directly or indirectly the environment and a wide series of sectors, the reality today is one questioned by how can we prevent or cope with the adverse effects thereof. It results in a striking need to develop tools for simulating impacts of climate change on as many areas of interest. In this way interested stakeholders and persons responsible for decision making will have access to credible scientific information and worth of consideration.

There is an increasing interest for developing integrated assessment platforms (IA) to meet the needs of decision makers by providing relevant scientific information that they might consider in the process of decision making. In terms of response times, there are two types of integrated assessment platforms: fast response platforms, such as CLIMSAVE IAP, and delayed response platforms, such as IMPRESSIONS dIAP. These two platforms were developed during my PHD study years and together with the methodologies on which they rely on form a solution to the problem of climate change, problem to which my thesis has tried to respond.

CLIMSAVE IAP is a PIA (participatory integrated assessment) platform as many stakeholders have been involved in the process of developing, assessing and exploring socio-economic scenarios as well as in the calibration and testing process of the interactive platform. As an online platform, CLIMSAVE IAP innovates through its flexibility, accessibility and its rapid and extensive familiarity of its interface.

Thus, by applying a simplified approach of integrated sectorial models validated by stakeholders at all levels of the process and by developing an online GUI platform available to any potential users, CLIMSAVE IAP can be considered a valuable e-learning tool that can help raise accountability of a vast community of individuals from pupils, students and reaching to important people in decision-making positions. The inclusion of the IAP in the European Climate Adaptation Platform [**57**] constitutes a proof of credibility and an attempt to encourage citizens to use the platform even if, at first, it is only for curiosity reasons. The novelty of this platform is that it allows users to explore and understand the interactions between various sectors rather than viewing the sectorial area in isolation, giving them the opportunity to improve their quality of life.

Although high-end scenarios are extremely plausible, there are relatively few studies or tools to evaluate their possible effects and provide solutions to reducing or adapting to these impacts. Given the fact that current methods and modeling tools meet many limitations and problems in running in terms of a disastrous scenario, it appeared the need to develop a calibrated system to operate in extreme conditions, thus enabling decision-makers to have access to credible scientific information. IMPRESSIONS dIAP attempts to answer to as many challenges and needs as possible by developing an innovative research methodology that guides those interested step-by-step in the processes of representation, quantification and mapping the sectorial impacts of high-end scenarios. This new methodology resulted in the development of an online platform that is based on the methods, meta-models and datasets developed in the best existing research projects which face the same problem: that of taking into consideration a single sector.

IMPRESSIONS dIAP aims to simulate the effects of high-end scenarios (no turning back scenarios) that have been defined in a participatory manner with the help of stakeholders. It also aims to draw attention over the potential devastating effects that climate change can have on a wide range of sectors (urban, hydrological, forest, coastal, agricultural, biodiversity). Enabling possible ways of adapting, dIAP can be viewed as a platform with potential wide usage that can lead to an improved quality of life and environment.

The novelty brought by IMPRESSIONS dIAP consists especially in the simulation time of the meta-models and their dynamics. So, if its parent – the CLIMSAVE IAP - could simulate the effect of climate change for one period of time, be it the current (Baseline), 2020 or 2050, dIAP runs dynamically for nine decades (2010-2100). This dynamic consists in the fact that the meta-models can take account for the values obtained in past decades either by themselves or by other meta-models with which they interact.

Both platforms have been and can be used as learning and e-learning tools by raising tomorrow's generation of decision-makers to be aware of the impact of climate change and the measures that can be taken to limit them.

5.1 Personal contributions

My personal contributions and the actions that I have performed during the years in which I elaborated my thesis are as follows:

- I have studied climate change literature, existing platforms and models to assess their impact on mankind.
- I received feedback following the development of the TESSA mobile application elaborated during my Master period and implemented the necessary modifications and updates. The application was described in section 2.6 and the results were disseminated in [**45**].
- I designed the standardized data dictionaries specific to each integrated meta-model within CLIMSAVE IAP platform. For this purpose, I had to follow an iterative and repetitive process of direct interaction with meta-models' developers. This process was described in section 3.5.3.4.
- In IMPRESSIONS dIAP I contributed to the quantification, development and calibration of both climate and socio-economic scenarios through a process of testing

and validating the data received from scenario experts or modelers. So, if climate and socio-economic data did not have the correct resolution or were not sufficient to provide meta-models with the necessary inputs, I got in touch with the people responsible to solve the shortcomings and provide the correct data. For some socio-economic quantifications, up to five intermediate versions were required to reach the final one. This contribution was detailed in section 4.4.

- For IMPRESSIONS dIAP I contributed to the development of the platform methodology and to the analysis and specification of the platform's requirements. This contribution was described in section 4.2 and disseminated in [**47**].
- I designed IMPRESSIONS dIAP platform's architecture. I decided that the two user graphical interfaces (Input and Output) of the platform should be separated one from another (delayed response platform). These actions were detailed in sections 4.5.1 and 4.5.2 and disseminated in [**46**].
- I designed and implemented the graphical user Input Interface for IMPRESSIONS dIAP. This contribution was described in sections 4.5.3.2 and 4.5.3.3 and disseminated in [**46**].
- In IMPRESSIONS dIAP, I have redesigned the structure of the data dictionaries specific to each meta-model by including a way of passing information from one decade to the next, be it from one meta-model to another or from one meta-model to itself. The development of the data-dictionaries followed an iterative and repetitive process in which I had directly interacted with model developers. This action was detailed in section 4.5.4.
- After finalizing the data dictionaries, I have established the running order of the meta-models in IMPRESSIONS dIAP. This contribution was synthetized in section 4.5.4.
- I contributed to the elaboration and calibration of the methodology behind the Urban model integrated in IMPRESSIONS dIAP, particularly to its algorithmization. This contribution was described in section 4.5.4.1.1 and in Annex 4.
- I identified the need to store input data, especially climatic and socio-economic quantifications in a relational database. I modeled, implemented and loaded into this database the required data for IMPRESSIONS dIAP. The structuring and formatting of the inputs were also done by me. These actions were detailed in section 4.5.1 and disseminated in [**46**].
- For IMPRESSIONS dIAP, I organized and structured the necessary input and output data streams. These contributions were described in section 4.5.4 and disseminated in [**46**].
- For IMPRESSIONS dIAP, I designed and implemented the *Control Module* on which the platform relies on, using the data dictionaries, the input data stored in the database and the established meta-models run order. Putting them together and implementing a common and unitary meta-model communication and interconnection was one of the greatest challenges. These actions were described in sections 4.5.1 and 4.5.2 and disseminated in [**46**].
- For both IMPRESSIONS dIAP and CLIMSAVE IAP, I have provided technical support to modelers who have encountered difficulties in implementing their meta-

models in the standardized format for an easy integration with the platform. This action was detailed in subsections 3.5.3 and 4.5.4 disseminated in [**47**].

- I collaborated on creating the design of the IMPRESSIONS dIAP Output Interface and on establishing the components and functionalities to be included in it. The result of this collaboration was detailed in section 4.5.3.4 and disseminated in [**46**].
- I have run a series of batch scenarios on CLIMSAVE IAP and obtained the results used in the development of sensitivity analysis, uncertainty analysis, and identification of the cross-sectorial impacts of climate change. Because batch runs do not allow a graphical view of the results, as the information is exported into files with sizes that exceed 2 GB I have designed an algorithm that parses and extracts the results in files that can be plotted using any map service. This contribution and its results were described in section 3.6.2 and disseminated in [**18**], [**22**], [**5**], [**65**] and [**48**].
- I tested and verified the proper functioning of both platforms. I signaled the problems and the bugs and I have provided help and assistance to the modelers in order to solve them. These operations were detailed in sections 3.6 and 4.6 and disseminated in [**44**].
- I am the person responsible for the maintenance and the implementation of possible changes to IMPRESSIONS dIAP.

5.2 Future work

In the same way as IMPRESSIONS dIAP came as a continuation and improvement of CLIMSAVE IAP by extending climate change simulations until 2100, running meta-models in a time-dependent manner or saving decadal results and calibrating the new ones on them, new platforms can be developed starting from these two platforms. The new platforms can be developed keeping the same European resolution or can be applied locally at country scale or even globally. Also, the socio-economic and climatic scenarios included in the two platforms can be updated or adapted to new requirements by inserting new data in the database and making minor changes in the graphical user interface components. Updates or even replacements of the meta-models included in both platforms can bring great improvements to the platforms and to the available simulations.

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7 ANNEXES

Annex 1 – CLIMSAVE IAP Impact input indicators

Social:

Input Indicator	CLIMSAVE IAP tooltip description	Result if indicator is increased
Population change	Change in Population	Population increase Increased need of food Increased need of water
Water savings due to behavioral change	Water savings due to behavioral change to use less water (negative values imply increasing water use due to more water-intensive behavior).	Reduces the need for household water
Change in dietary preference – beef/lamb	Reflects the change in preference and demand for largely grass-fed meat.	Increase area covered with grass
Change in dietary preferences - chicken/pork	Reflects the change in preference and demand for largely grain-fed meat	Increase in agricultural area
Household externalities preference	Reflects people’s relative desire to live in rural areas with access to green space (1), or urban areas with access to social facilities (5).	Urban artificial area increase

Table 7.1 CLIMSAVE IAP - Social Impact Input Indicators

Technological:

Input Indicator	CLIMSAVE IAP tooltip description	Result if indicator is increased
Change in agricultural mechanization	Change in the amount of labor-saving mechanization.	Crop change Reduced production expenses
Water savings due to technological change	Water savings in domestic and industrial water demand due to technological improvements.	Increase water available for agriculture
Change in agricultural yields	Changes in crop yields due to crop breeding and agronomy (leading to increases) or environmental priorities (leading to decreases).	Productivity increase
Change in irrigation efficiency	Changing the amount of water used to produce a fixed amount of food.	Productivity increase Increased irrigation profitability

Table 7.2 CLIMSAVE IAP - Technological Impact Input Indicators

Economic

Input Indicator	CLIMSAVE IAP tooltip description	Result if indicator is increased
Change in bioenergy production	Represents more land allocated to agricultural bioenergy and biomass crops (and so less for food and nature) or vice versa.	Less agricultural areas for food production
Change in food imports	Change in food imports, relative to 2010.	Reduced agricultural areas
GDP change	Change in Gross Domestic Product, relative to 2010.	Increased salaries High food prices
Change in oil price	Change in oil price, relative to 2010.	Increased costs for agriculture Crop change

Table 7.3 CLIMSAVE IAP - Economic Impact Input Indicators

Environmental

Input Indicator	CLIMSAVE IAP tooltip description	Result if indicator is increased
Human capital	Proportion of arable land set-aside for biodiversity.	Reduced agricultural area
Reducing diffuse source pollution from agriculture	Reducing crop inputs, such as fertilizer N and pesticides.	Reduced crops Reduced productivity
Coastal flood event	The coastal flood event return period for which flooding impacts are calculated.	Increased flood impact
Fluvial flood event	The fluvial flood event return period for which flooding impacts are calculated.	Increased flood impact
Forest management	Dominant management approach for each tree species - optimum, even-age (clear-felling and re-planting to give uniform age distribution) or uneven-aged (patch cutting and planting to produce age distribution).	Change in forest productivity

Table 7.4 CLIMSAVE IAP - Environmental Impact Input Indicators

Policy governance

Input Indicator	CLIMSAVE IAP tooltip description	Result if indicator is increased
Compact vs. sprawled development	Planning policy to control urban expansion and so protect land availability for food and biodiversity through, for example, planning restrictions and requirements, tax measures.	Increase in artificial areas
Attractiveness of coast	Preference for living at the coast.	Increase in artificial areas near coasts
Water demand prioritization	How water should be prioritized when demand is greater than availability (giving priority to food production, environmental needs).	Direction for water prioritization
Level of Flood Protection	No flood protection – exploratory option that assumes there are no flood defences in place. Minimum represents indicative estimates of flood protection based on land use/land cover and available flood protection .	Increased flood impact

Table 7.5 CLIMSAVE IAP - Policy Governance Impact Input Indicators

Annex 2 – CLIMSAVE IAP Sectorial Output Indicators

Sector	Indicator/Subsector	Indicator
Biodiversity	Common poppy	
	Linnet	
	Bilberry	
	Hornbeam	
	Norway spruce	
	Brown bear	
	Western dappled white butterfly	
	Common saltmarsh grass	
	Strawberry clover	
	Bell heather	
	Red dear	
	Capercaillie	
	Shannon Biodiversity Index	
	Boreal needle leaved evergreen tree	
	Silver fir	
	Norway Spruce	
	Scots Pine	
	Protected Areas	
	Number of species present	
	Biodiversity Vulnerability Index	
Tourism	Days with 3 cm snow cover	
	Days with 10 cm of snow cover	
Coping Capacity	Coping Capacity	
	Social Capital	
	Human Capital	
	Financial Capital	
	Manufactured Capital	

Table 7.6 CLIMSAVE IAP – Biodiversity, Tourism and Coping Capacity Output Indicators

Sector	Indicator/Subsector	Indicator
Pests	**Ecoclimatic Index**	English grain aphid
		Cereal leaf beetle
		Colorado Potato Beetle
		Codling moth
		Bird cherry-oat aphid
		European grapevine moth
		European corn borer
	Number of generations	English grain aphid
		Cereal leaf beetle
		Colorado Potato Beetle
		Codling moth
		Bird cherry-oat aphid
		European grapevine moth
		European corn borer
Forestry	Potential Wood Yield	
	Leaf Area Index	
	Total cross-sectional trunk area	
	Potential Gross Primary Production	
	Potential Net Primary Production	
	Potential Net Ecosystem Exchange	
	Potential Above ground biomass	
	Potential Carbon stock	
	Potential Water stored in the soil	
	Potential Soil Organic matter	
	Forest productivity	Managed forest yield
		Unmanaged forest NPP
		Forest area
		Managed forest area
		Unmanaged forest area

Table 7.7 CLIMSAVE IAP – Pests and Forestry Output Indicators

Sector	Indicator/Subsector	Indicator
Habitat/Land cover	Areas of saltmarsh	
	Areas of intertidal flats	
	Areas of inland marsh	
	Areas of coastal grazing marsh	
	Urban	
	Intensively farmed	Percent of grid(IF)
		Yearly Productivity(IF)
		Leaf Coverage(IF)
		Biomass(IF)
	Extensively farmed	Percent of grid(EF)
		Yearly Productivity(EF)
		Leaf Coverage(EF)
		Biomass(EF)
	Unmanaged land	Percent of grid(UL)
		Yearly Productivity(UL)
		Leaf Coverage(UL)
		Biomass(UL)
	Forest	Percent of grid(F)
		Yearly Productivity(F)
		Leaf Coverage(F)
		Biomass(F)
Flood	Medial annual flood discharge	
	Area at risk flooding	
	Threatened people	
	People flooded	
	Damages due to flooding	
	People flooded in a 1 in 100 year event	
Urban	Artificial surfaces	
	Residential area	
	Non-residential area	

Table 7.8 CLIMSAVE IAP – Land Cover, Flood and Urban Output Indicators

Sector	Indicator/Subsector	Indicator
Agriculture	Land cover types	Intensively farmed
		Arable crops
		Stubble area
		Extensively farmed
		Unmanaged land
		Managed forest
		Unmanaged forest
		Flood zone
	Indicators	Food production
		Food per capita
		Fiber production
		Timber production
		Land use diversity
		Intensity index
	Crop inputs/outputs	Irrigation usage
		Fertilizer usage
		Pesticide usage
		Nitrate losses
	Yields	Winter wheat
		Spring wheat
		Winter barley
		Spring barley
		Potatoes
		Sugar beet
		Winter oilseed rape
		Summer oilseed rape
		Maize
		Forage maize
		Cotton
		Sunflower

Table 7.9 CLIMSAVE IAP – Agriculture Output Indicators

Sector	Indicator/Subsector	Indicator
Agriculture	**Yields**	Soya
		Grass
		Permanent grass
		Extensively grass
	Area	Winter wheat
		Spring wheat
		Winter barley
		Spring barley
		Potatoes
		Sugar beet
		Winter oilseed rape
		Summer oilseed rape
		Maize
		Forage maize
		Cotton
		Sunflower
		Soya
		Grass
		Permanent grass
		Extensively grass
Water	Water availability	
	Falkenmark index	
	Median annual flood discharge	
	Water price increase	
	Average discharge	
	Low-flow discharge	
	High-flow discharge	
	Water exploitation index	
	Manufacturing water withdrawls	
	Total water use	

Table 7.10 CLIMSAVE IAP – Agriculture and Water Output Indicators

Annex 3 – IMPRESSIONS socio-economic scenarios

Four socio-economic scenarios were selected within IMPRESSIONS project and were chosen to match such high-end scenarios contexts. They are as follows:

- SSP1 - taking the green road - scenario characterized by:
    - local, national and international collaboration between public organizations and the private system
    - population decline
    - welfare of the population even if it is followed by a decline in economy
    - reduction of inequalities between people, both at country level and internationally
    - efficient use of resources that will lead to long-term improvement of environmental conditions
    - developing environment-friendly technologies
    - reduced resource consumption
    - attempt to use renewable energy sources
- SSP3 - the rivalry road - has the following main features:
    - regional development
    - potential conflicts between regions
    - increasing competition between regions
    - global division induced by the existence of weak international organizations
    - safety policies targeted at the regional/national level
    - increased emphasis on agriculture and exploitation of resources
    - possible authoritarian regimes in some areas in view of strengthening and growth of the region in the surrounding regional hierarchy
    - decrease in investments in education and technology
    - increased consumption
    - inequality increase
    - economic decline
    - decreasing importance on environmental protection
    - increased dependence on fossil fuels and resources
- SSP4 - the inequality road - main features:
    - unequal human capital investment
    - population stratification
    - separating the population into two sectors:
        - one well-educated and globally interconnected, producer of solid capital
        - one poorly educated working in menial jobs, producer of a low capital
    - political and business elitism
    - moderate economic growth levels in industrialized countries and lower levels in countries with low capital
    - increased conflict potential
    - technological development

    - rising fossil fuel prices
- SSP5 - Fossil-Fueled Development - scenario characterized by:
    - economic success
    - competitive markets
    - technological advances
    - social and human capital development
    - decreasing inequality between people
    - investments in education and health
    - exploitation of fossil fuels and adopting a lifestyle dependent on them
    - economic growth
    - nativity and population decline
    - hope to reduce environmental impacts through technology solutions
    - lacking policies for protecting the environment

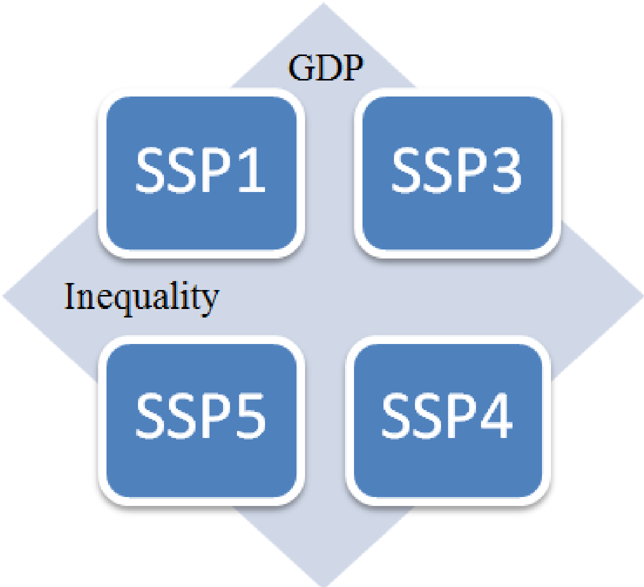

Figure 7.1 IMPRESSIONS Socio-economic scenarios

Annex 4 - RUG Meta-model component structure and workflow

1. **Module 1**:
   - *Module1_Input*: NUTS2 data, User parameters, Scenario, Timestep
   - *Method*: Calculate Population Count for each residential type at NUTS2 level at the current time step, and determine the required Artificial Surface (AS) increase for each urban type in order to satisfy the growth of population.
   - *Module1_Output*: AS required increase for each residential type at NUTS2 level, Population Count for each residential type at NUTS2 level
2. **Module 2**:
   - *Module2_Input*: NUTS2 data, CELL data, User parameters, Scenario, Time step
   - *Method*: Calculate the transition potential for each CELL in NUTS2.
   - *Module2_Output*: Transition potential for each urban type for each CELL in NUTS2
3. **Module 3**:
   - *Module3_Input*: CELL data, Timestep, Module1_Output, Module2_Output
   - *Method*: Spatially allocate the AS required extent for each residential type, obtained in Module 1, at CELL level.
   - *Module3_Output*: AS extent for each residence type for each CELL
4. **Module 4**:
   - *Module4_Input*: CELL data, Module3_Output
   - *Method*: Generate required output at CELL level: Population per age group, Total population, AS for each residential type, total AS.
   - *Module4_Output*: at CELL level : AS per residential Type 1,2,3,NR(%), Population per Age group 1-6, Total AS surface, Total Population Count

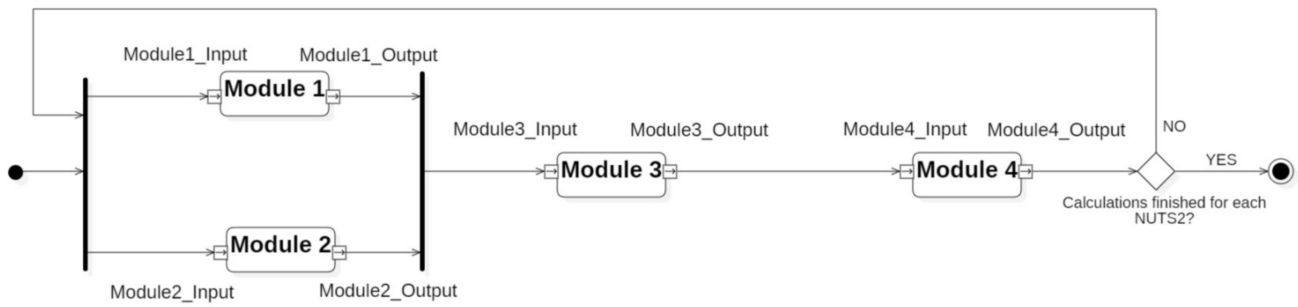

Figure 7.2 RUG execution flow (UML activity diagram)

8 LIST OF ACRONYMS

A1B	Balanced emission scenario (IPCC SRES)
A1FI	Fossil fuel intensive emission scenario (IPCC SRES)
A1T	Non-fossil fuel intensive emission scenario (IPCC SRES)
AS	Artificial Surface - output for RUG model
ATEAM project	Advanced Terrestrial Ecosystem Analysis and Modelling
CFFlood model	Coastal River Flood model
CLIMSAVE IAP	CLIMSAVE Integrated Assessment Platform
CORDEX	Coordinated Regional Downscaling Experiment
CORINE	Coordination of Information on the Environment
DICE model	Dynamic Integrated model of climate and the Economy
DLL	Microsoft Dynamic-Link Library
DPSIR	Driver-Pressure-State-Impact-Response
EU	European Union
Eurostat	Statistical Office of the European Communities
GCM	Global Climate Model
GDP	Gross Domestic Product
GOTILWA model	Growth Of Trees Is Limited by water model
IA	Integrated Assessment
IDC	International Data Corporation
IIASA	International Institute for Applied Systems Analysis
IMPRESSIONS dIAP	IMPRESSIONS dynamic Integrated Assessment Platform
IPCC	International Panel on Climate Change
IPCC SRES	International Panel on Climate Change Special Report on Emission Scenarios
IWRM	Integrated Water Resource Management
MA	Millennium Ecosystem Assessment
MOTIVE project	MOdels for AdapTIVE forest Management
NeWater project	New Approaches to Adaptive Water Management under Uncertainty
NUTS2	Nomenclature of Territorial Units for Statistics - Second level
PIA	Participatory Integrated Assessment
R1	Cities (densely populated areas); Residential type 1 used in RUG
R2	Towns and suburbs (intermediate density areas); Residential type 2 used in RUG
R3	Rural areas (thinly populated areas); Residential type 2 used in RUG
RCM	Regional Climatic Model
RCP	Representative Concentration Pathway
Riders	Riders on the Storm socio-economic scenario developed in CLIMSAVE project
RUG model	Regional Urban Growth model
SFARMOD-LP	Silsoe Whole Farm Model
SLR	Sea Level Rise
SoG	Should I Stay or Should I Go socio-economic scenario developed in CLIMSAVE project

SPECIES model	Spatial Estimator of the Climate Impacts on the thumb of Species
SSP	Shared Socio-economic Pathway
SSP1	First Shared Socio-Economic Pathway for IMPRESSIONS dIAP - taking the green road scenario
SSP3	Third Shared Socio-Economic Pathway for IMPRESSIONS dIAP - the rivalry road scenario
SSP4	Fourth Shared Socio-Economic Pathway for IMPRESSIONS dIAP - the inequality road scenario
SSP5	Fifth Shared Socio-Economic Pathway for IMPRESSIONS dIAP - Fossil-Fueled Development scenario
TaiCCAT program	Taiwan integrated research program on Climate Change Adaptation Technology
TESSA	Toolkit for Ecosystem Service Site-based Assessment
UNEP-WCMC	UN Environment World Conservation Monitoring Centre
UNFCCC	United Nations Climate Change
WCF-RIA	Windows Communication Foundation - Rich Internet Application
WRW	We Are The World socio-economic scenario developed in CLIMSAVE project
Yield-SAFE	Yield Estimator for Long term Design of Silvoarable Agroforestry in Europe