Experience from the Use of the Interactive Model- and GIS-based Information and Decision Support System *LandCaRe-DSS* for the Development of Economic Effective Application Strategies of Agriculture to Climate Change

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Abstract The expected change of climate will influence agriculture in a multifactorial manner. Up to now there are few suitable tools and methods for agricultural farms and other decision makers to give helpful answers on questions like: How will climate change influence regional agriculture and ecosystems and what will be possible adaptation strategies for agriculture. The newly developed information and decision support system, called LandCaRe-DSS, closes this gap. It is designed as a user friendly, interactive, model-based, and spatial-oriented information and decision support system, can be used on different spatial scales, and supports long-term and ensemble simulations on a high spatial resolution. The LandCaRe-DSS system assists strategic planning in agriculture and sustainable development of rural areas (regions) and provides answers concerning the effects and costs of possible adaptation measures. Being still a prototype, LandCaRe-DSS is parameterized and validated for two German regions at present. The impact models used in LandCaRe-DSS, the experience of collaboration with stakeholders, and the possibilities and limitations of the LandCare-DSS are described just like practical experience gathered during the system development from the modelling and implementation point of view. First results of scenario simulations based on different climate regionalization methods are presented and discussed.

1 Introduction

Agriculture is a fundamental human activity, supporting the livelihood of everyone on this planet. Of the nearly 14 billion hectares of ice-free land on Earth, about 10% are used for crop cultivation, while an additional 25% of land is used for pasture. Over 2 billion tons of grains are produced yearly for food and feed, providing

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roughly two-thirds of total direct and indirect protein intake; a mere 10% of this total, or 200 million tons, is traded internationally (Tubiello et al, 2007).

Perhaps the most important challenge that agriculture will face in coming decades is represented by the need to feed increasing numbers of people while conserving soil and water resources. Existing projections indicate that future population and economic growth will require a doubling of current food production, including an increase from 2 up to 4 billion tons of grains annually, without significantly increasing current arable land.

At the same time there is a significant concern about the impacts of climate change and its variability on agricultural production worldwide. Current research confirms that many crops would respond positively to elevated CO_2 but the associated impacts of high temperatures, altered patterns of precipitation and possibly increased frequency of extreme events such as drought and floods will probably combine to depress yields and increase production risks in many world regions, widening the gap between rich and poor countries (IPCC, 2007).

Most of the discussion on climate change up to now has focused on mitigation measures, for example the Kyoto Protocol. Not much attention has been given to climate-change adaptation, which will be critical for many developing countries but also for many regions in Europe. Each country should examine separately, how it can reduce their vulnerability to climate change and increase desirable outcomes with the lowest costs under consideration of the different regional and local economic and soil-climate conditions.

Adaptation to climate change requires resilient knowledge on the potential regional and local impacts of climate and weather extremes. Effects of climate change on agriculture may be positive or negative, depending on the variability of weather conditions, site quality, land use and management. Adaptation must consider sustainability with respect to high plant production without loosing different ecosystem services like soil protection, purification and recycling of water or maintenance of biodiversity. Further, adaptation measures should not enhance climate change but reduce greenhouse-gas emissions. That implies decision making to consider both socio-economic and ecological consequences of adapted management.

Recent developments in geographical information systems, in the development of robust climate impact models, but also better technologies for data acquisition, have enabled modelling to identify potentials and environmental constraints to crop production at regional and national levels regarding the expected climate change. By integrating models in interactive usable decision support systems, farmers and other stakeholders have a framework, which can be used to find answers related to the most appropriate management practices to adjust the agriculture to the climate change.

Because there is a lack of good model based decision support systems for climate adaptation of agriculture on the regional and local scale, five years ago in Germany the now finished joint research project LandCaRe 2020 (Land, Climate and Resources) had been started. LandCaRe 2020 (www.landcare2020.de) investigated effects of regional climate change on agricultural production as well as water and matter fluxes to provide a knowledge-based framework for adaptation. The project consisted of ten sub-projects co-ordinated by the Department of Meteorology at the

Technical University of Dresden and conducted at six research institutes in Germany. Funding had been provided by the German Ministry for Education and Research within the funding program "Research for climate protection and protection from climate impacts".

Central objective of the project LandCaRe 2020 was a web-based, dynamic decision support system (dDSS), known as LandCaRe-DSS, exemplarily developed for two contrasting regions of Eastern Germany (dry lowlands of the State of Brandenburg and a humid mountain area of Free State of Saxony). The conceptual framework and the integration of different modules within the LandCaRe–DSS are represented in Figure 1.

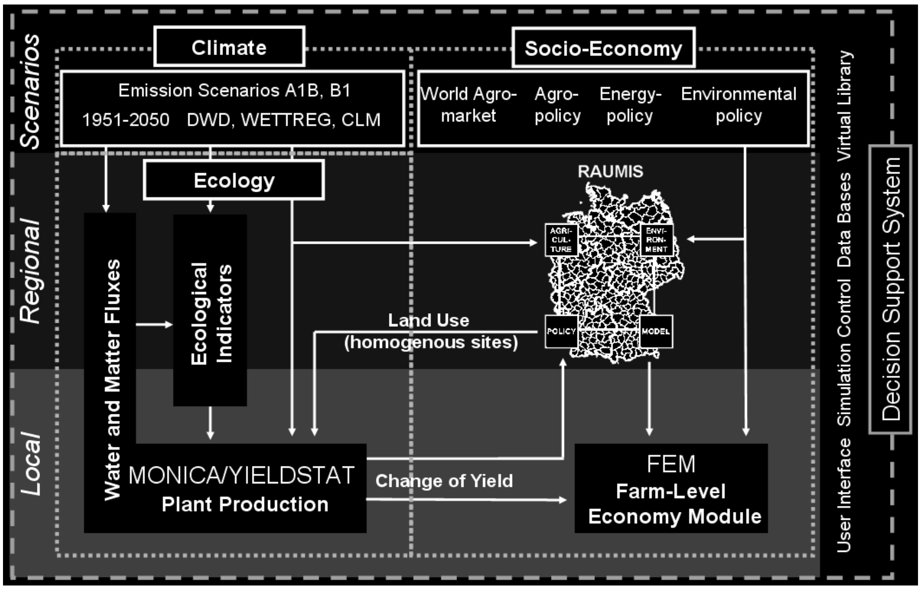

Fig. 1. Conceptual framework and levels of integration of different modules in the LandCaRe-DSS

2 Methods and Materials

System Structure and Characteristics

The LandCaRe-DSS consists of five basic system components:

- Information and advisory system,
- Analysis of climate data and climate impacts on plant phenology,

- Climate change impact assessment for agriculture on national level,
- Climate change impact assessment on regional and farm level,
- Simulation and integrated assessment of different agricultural adaptation strategies to climate change.

The basic principle of operation, which can be characterized as an iterative procedure from the scenario definition, the evaluation of different agricultural farm management adaptation strategies, up to decision, what is the best adaptation strategy for the concrete farm, is shown in Figure 2.

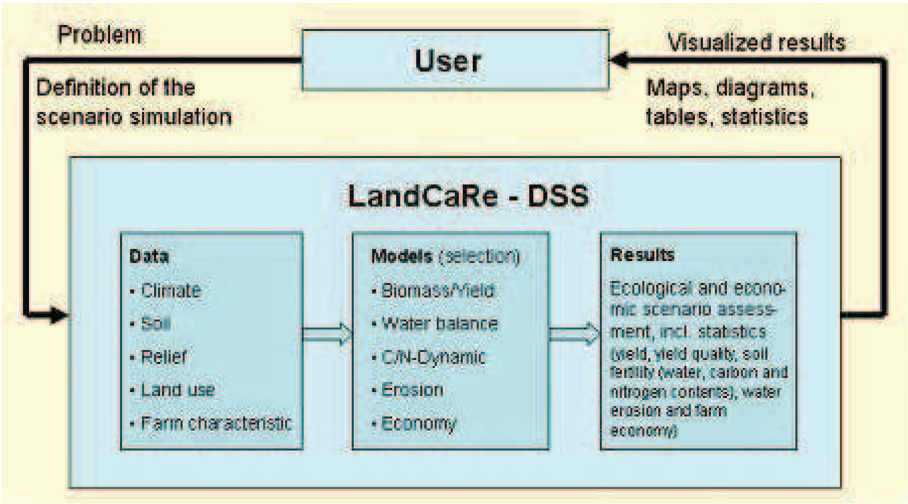

Fig. 2. Basic principle of operation of LandCaRe-DSS

As distinguished from other Decision Support Systems (DSS) the LandCaRe-DSS offer the following special features:

- Interactive
  (The user decides which simulations and calculations to execute and runs almost all models by himself.)
- Dynamic
  (A large variety of simulations can be run, analyzed and compared with each other by the user. The chosen preconditions will affect the simulation results.)
- Spatial-oriented
  (The user chooses the desired level of detail by zooming between national, regional or farm level. Based on this choice different models can be activated for execution.)
- Web-based
  (Central support, control and update of the entire DSS software and all supporting data)
- Extendable
  (Open for further add-ons; frequent update of information, knowledge and data.)

Short Description of the Functionality

As a prerequisite for the development of a DSS, potential users like agricultural administrations, farmers, water agencies and agro-businesses were included in the research process. As far as possible their specific demands of knowledge and decision support could be considered. The spatial DSS is interactive and dynamic, because it allows new model runs with various sets of scenarios and parameters by the user. It includes regional climate trends and weather statistics of the past, recorded by climate stations of the German Weather Service (DWD) since 1950, as well as different future climate scenarios based on the ECHAM5 Global Circulation Model with dynamic downscaling steps (20 to 1 km grid length) using the Europe-wide regional climate model CLM (Böhm et al. 2006) and results of the statistical-dynamic model WETTREG (Enke et al. 2005). Besides multi-ensemble climate scenarios, socio-economic scenarios are provided by the agricultural information system RAUMIS to derive the actual and potential future land use and to provide data for the transfer of the system to other regions in Germany. The module "ecology" comprises simulations of water, carbon and nitrogen fluxes as well as yield predictions of agricultural crops and grassland. Simulations are performed by the central, CO_2-sensitive model MONICA (MOdel for NItrogen and Carbon in Agro-ecosystems, Nendel et al., 2011) developed from components of previous in ZALF developed models like THESEUS (Wegehenkel et al, 2004), HERMES (Kersebaum, 2007) and AGROSIM (Mirschel & Wenkel, 2007). Further models and algorithms are used to derive ecological indicators related to nitrogen and water fluxes, water-use efficiency, primary production, greenhouse-gas emission, soil erosion and site potential. Modelling is supported by data from FACE (free-air carbon dioxide enrichment) experiments with agricultural crop rotations at vTI Brunswick. Besides completed experiments with the C3-species sugar beet, wheat and barley, the C4-species maize is currently investigated under high CO_2 (550 ppm). The experiments allowed it to include the CO_2 fertilizer effect in modelling which is crucially important for the prediction of crop yield with respect to quality, quantity and implications on the soil water and energy budget. The project is open for participation in the user panel and collaboration with other related projects. At the end of the project, the LandCaRe-DSS verified for the two exemplary regions was converted into an operative web-based version (http//:www.landcare-dss.de). The model framework, adapted software and a defined set of required data provide for future transfer to other regions.

Examples of LandCaRe-DSS Use

Analysis of Climate and Phenological Data

Information about the impacts of climate change on the ontogenesis of agricultural crops are very important for agro-management . Using the example of winter wheat, Figure 3 shows the lengths of different ontogenesis stages between sowing and harvest in comparison for two climate time periods. The DSS-user can chose different climate scenarios, different time periods and different sowing dates for running the ONTO model. In the result the DSS-user can see the crop reaction and can draw the consequences for agricultural measures, for instance in spring.

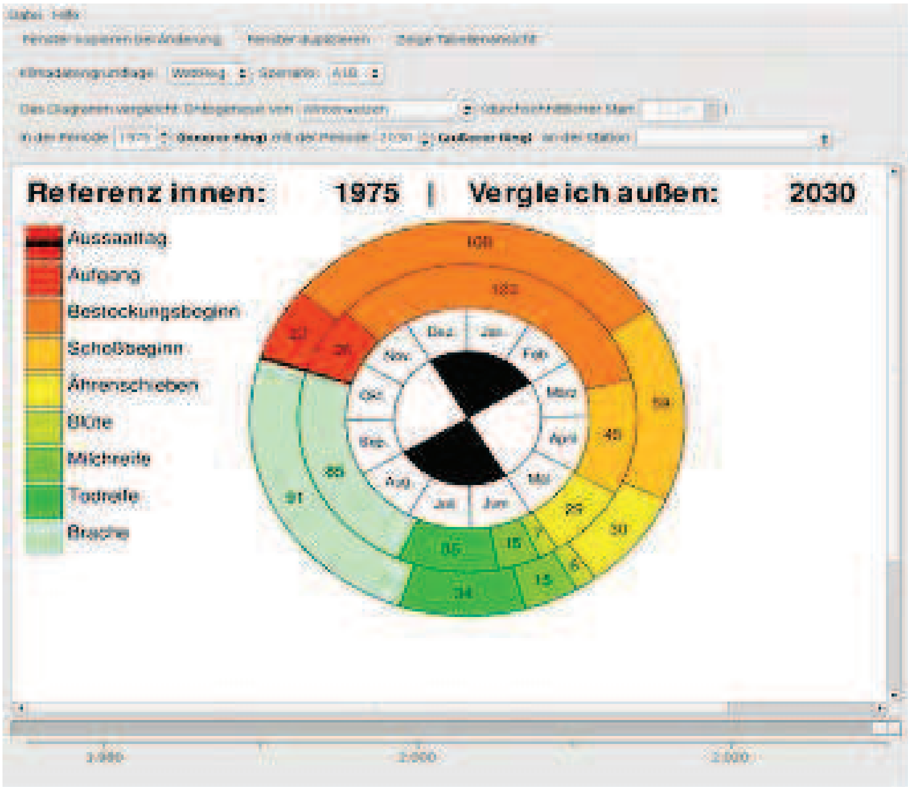

Fig. 3. Length of ontogenesis stages for winter wheat (in days) between sowing and harvest in comparison between 1975 (inner circle) and 2030 (outward circle).

Climate Change Impact Assessment on National Scale

At the national scale maps with information about changes in crop yields, cropping structure, farm economies and irrigation demand as a consequence of climate change are presented to the stakeholders for different time periods. The maps were created by the research group of vTI Brunswick. Within the LandCaRe-DSS the user can carry out a statistical analysis which is exemplary shown in Figure 4 (winter wheat yield at national scale for Germany with high resolution expected in 2025).

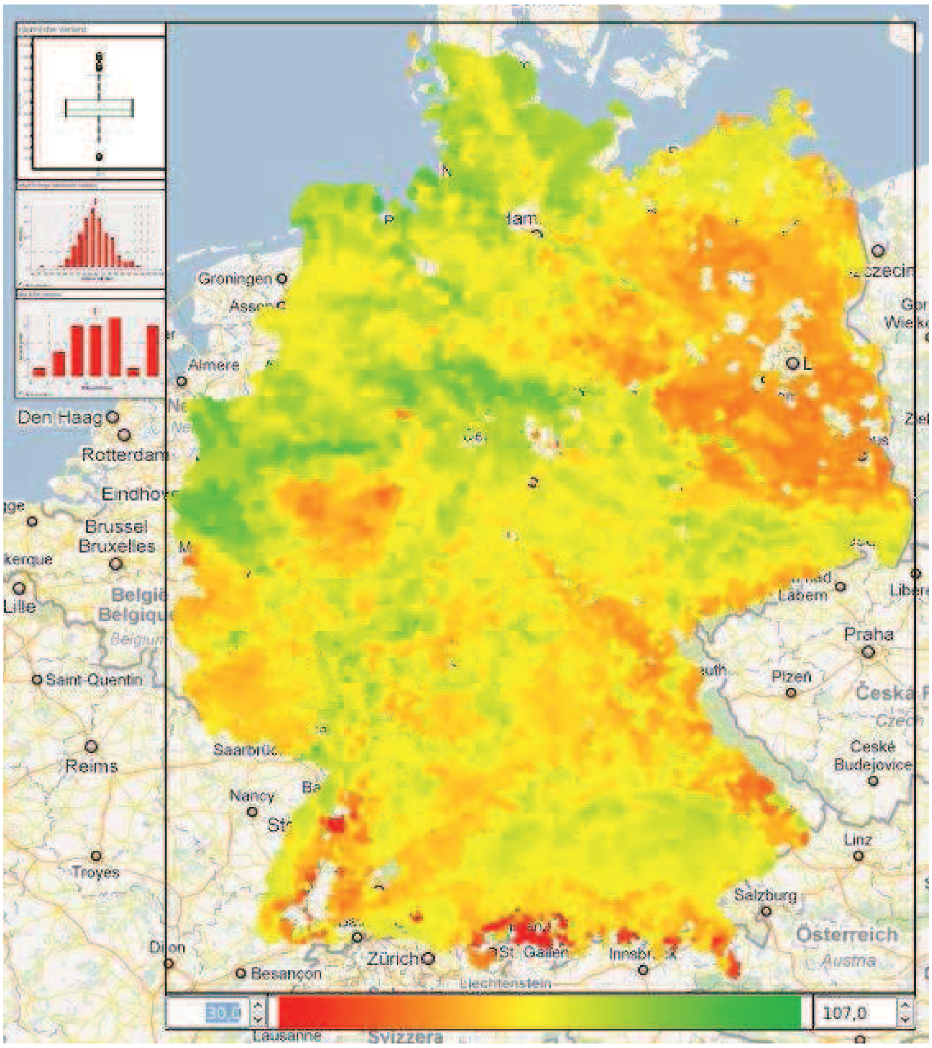

Fig. 4. Regional winter wheat yields for Germany in 2025 (results of the RAUMIS model simulation from vTI Brunswick)

Climate Change Impact Assessment on Regional Scale

On the regional scale the ecological impact assessment of climate and land use changes are realized on a high spatial resolution, i.e. on a minimum pixel size of 1 ha (100 x 100 m). Most of the models mentioned above can be activated on this level, but without a coupling to the economic model on this scale. Using different models calculations are possible for the expected impacts of climate change on yields for arable and grassland, on the potential erosion risk, on the regional actual evapotranspiration and the whole regional discharge, on the irrigation water demand and others. At this regional scale a statistical analysis (average, median, histogram …) is automatically realized. In Figure 5 for the Federal State of Brandenburg (BB) the irrigation water demand in 2000 (average for BB: 70.7 mm) is compared with the situation in 2080 (average for BB: 85.4 mm). From Figure 5 it is seen that in 2080 the irrigation area is significant larger than in 2000.

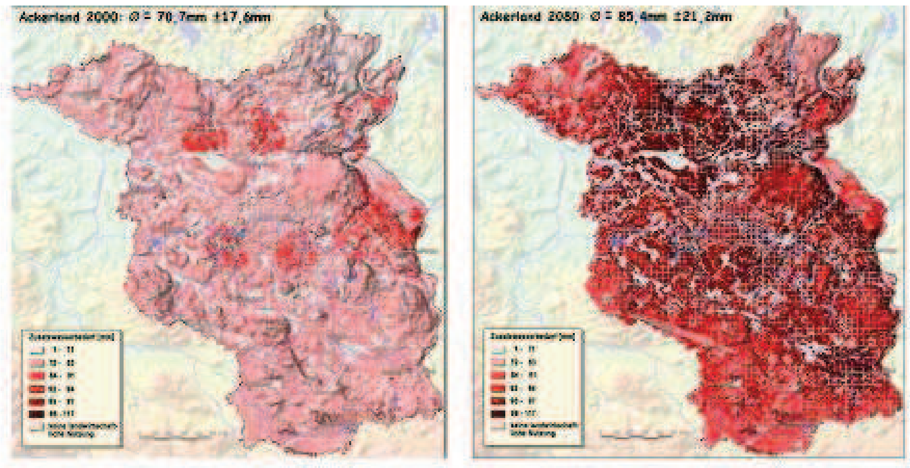

Fig. 5. Distribution of the irrigation water demand in 2000 (left) compared with the situation in 2080 (right) for the Federal State of Brandenburg (simulation with the model ZUWABE)

Local or Farm Scale

At local or farm scale an interactive simulation and integrated impact assessment of agricultural adaptation strategies to climate change (crop rotation, soil tillage, fertilization, irrigation, price and cost changes, …) is offered by the LandCaRe-DSS. The user of the system will be informed about changes of crop productivity (yield, yield quality), soil fertility (water, carbon and nitrogen contents), water erosion and farm economy. At farm level the MONICA and YIELDSTAT models are coupled to the farm economy model (FEM). The LandCaRe-DSS user receives information about different economic parameters, fertilizer amounts and costs, irrigation water demands and costs and finally about crop yields and sales profits. For all output information the variances of results are given based on up to 90 simulation runs. The results are visualized using normalized bar graphs for a better comparison between different scenario runs. Figure 6 shows an example for the visualized simulation results of the model MONICA for a small part of a farm, based at the Google-map background. The bar graphs are arranged around the fixed part of the farm which is subdivided in 1 ha (100 x 100 m) pixels. In the upper part first the data of the actual scenario run can be chosen. Secondly all input information can be activated and presented. At the left site of the figure there are shown parts of the dynamic results of

MONICA as average for the cropping year and as time course (for example the soil carbon dynamic) for the chosen 30-year time period.

3 Experiences and Conclusions

Most agricultural systems have a measure of built-in adaptation capacity („autonomous adaptation“) but the rapid rate of climate change will impose new pressures on the existing adaptation capacity. Interactive simulation und integrated impact assessment of agricultural adaptation strategies to climate change (crop rotation, soil tillage, fertilization, irrigation, price and cost changes, …) are very important prerequisites to support farmers and other stakeholders to find out cost effective adaptation strategies to climate change. Only a well informed user can make good decisions

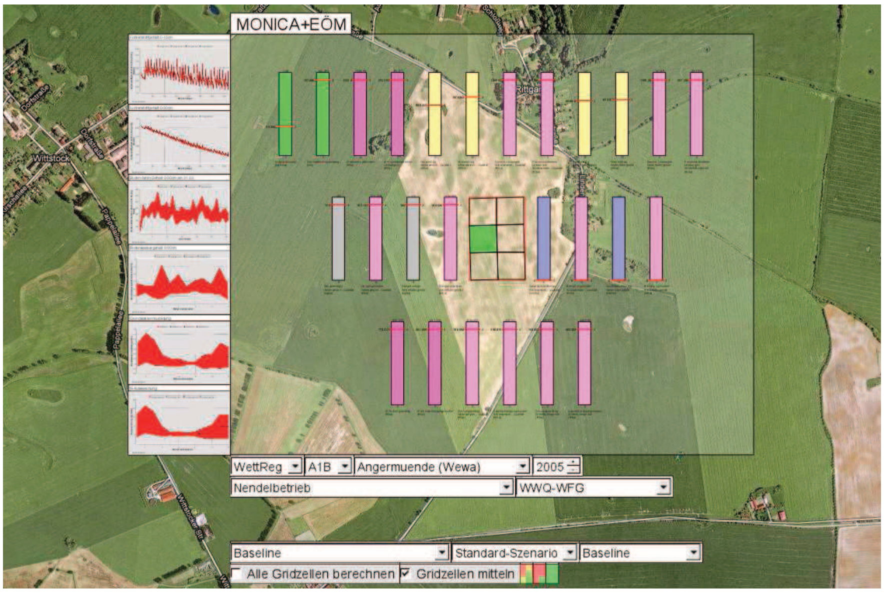

Fig. 6. Visualization of simulation results for the combined MONICA and FEM models at farm level for a small part of a farm within the Uckermark district, Germany.

The development of an interactively useable decision support system for climate change adaption makes high demands on the implementation concept as well as the modules included into the system. In order to support fast input/response cycles for climate scenario simulations (long term simulations; often necessary to run multiple times for decades), it is necessary to utilize the possibilities offered by modern multi-core computers and often to recode models, available in different programming-languages, into C++. Another prerequisite is to use a standardized interface to the shared GIS- and parameter database, which feed the models with all necessary parameters and input data.

Additionally some models had to be modified with regards to contents in order to make them fit for scenario simulations even in the limited presence of some regionalized climate variables (e.g. no availability of high temporal resolution precipitation events for the calculation of the RUSLE's R-factor in the erosion model). A further important experience is, that the models which are to be included into decision support systems have to be robust, well documented and above all have to be separately verified in space and time before their inclusion into the DSS framework. Trying to find programming mistakes or design errors in a model after the inclusion complicates things a lot due to the inherent dynamism build into the DSS and the sheer amount of parameter-combinations.

Because we can use in principle empirical, mechanistic as well as hybrid models for long term simulations (e.g. to assess the impacts of climate change on yield and biomass production for agricultural crops), the LandCaRe-DSS supports the possibility of multi-model-simulations. This is a prerequisite to assess the uncertainties resulting from different model types, yielding different simulation results with the same inputs.

Analogously LandCaRe-DSS can be used to evaluate the impacts of different climate scenarios (A1B, B1, A2, etc.) and different climate regionalization methods (e.g. CLM, WETTREG, STAR2) onto the simulation results. Experiences from recent climate impact studies show, that different regionalization methods lead to different projections of the main important climate elements (radiation, temperature and precipitation) in time. Because all projections are of the same probability and interact with the impact-models, the only way to estimate the possible bandwidth of regional climate changes onto the development of agricultural yields and other important landscape functions is to use multi-ensemble-simulations (simulations with data of different climate regionalization methods). For a decision support system this means, that it has to offer this functionality to the user in such a way, that he can pursue multi-model and/or multi-ensemble-simulations without difficulty. An implication of these possibilities is, that the decision support system has to prepare the often large amount of simulation results in such a way, that the user gains knowledge instead of is loosing track.

During the development phase of the LandCaRe-DSS a lot of work has been put into offering the user different kinds of context sensitive help to empower him to create and run the envisioned scenario simulations on his own. But the first results from the test phase show, that a reasonable use of such a complex model-based decision support system at the farm as well as the landscape planning level is only possible either involving the model's creators or specially trained people. Furthermore we have learned that a decision support system is never finished. With a growing user base also the requirements rise and/or change. Furthermore the scientific knowledge changes quickly and leads usually to new and more powerful models. This is especially true, if the system is being developed at the cutting edge. Thus only if it can be assured that the system's developer-team is able to complete and improve the system in the long term, it can be expected, that a complex decision support system can enter successfully into the real world.

Some important experiences could be attained on the first real applications of the models in climate and climate-impact studies regarding the quality of the geographical data in digital maps and climate projection data, offered by climatologists. Regarding the Geo-data it had to be observed, that often content doesn't match or locations are imprecise. This leads to problems during the automatic generation of inputs for the impact-models. Even more problematic is the fact that the climate projections of different climate regionalization methods sometimes differ heavily and extreme events which are of great importance for provision strategies either are not available at all, or their estimations are highly uncertain. These objectively existing uncertainties in the climate projection data lead to a large bandwidth of expected climate-effects and increase the difficulty in the search for cost effective climate adaption strategies. Making available more reliable regional climate projections which are better harmonized to each other thus proves to be a key duty for the climate-impact research and adaption of agriculture to the climate change in the future.

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