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COMPARING CLIMATE CHANGE ADAPTION RESEARCH IN AUSTRALIA AND THE NETHERLANDS; REVIEW OF THE VCCAP PROJECT

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Contents

1 Executive summary

The Victorian Department of Primary Industries (DPI) developed an extensive research program in collaboration with the Victorian Climate Change Adaptation Program (VCCAP). The aim of the program is to understand the potential impacts of climate change and develop Victoria's ability to respond. This review briefly describes this extensive research program and compares it to the ongoing Climate changes Spatial Planning (CcSP) research program in the Netherlands. Special attention is given to the LANDS project that aims to develop and implement a land-use modelling framework to define and integrate climate adaptation and mitigation measures.

Research on climate change, its implications and potential adaptation measures covers many different topics (climate, physical environment, socio-economic conditions, scenario development and planning) and thus calls for contributions from a wide range of disciplines. Such research can not be done in a single, isolated project, but requires a substantial effort of many different scholars, interaction with other relevant research institutions and an integrative research framework that is able to link the different constituting components. DPI VCCAP is a fairly complete research program that covers the most relevant aspects of climate change in relation to agricultural land use. With the current and anticipated future research efforts the program is likely to provide an increasingly useful contribution to formulating Victoria's response to climate change.

The building blocks of DPI VCCAP project are very similar to the Dutch Lands project. The land suitability assessment follows a robust approach which neatly incorporates the potential impact of climate change. Its input into a sophisticated, custom-made spatial optimisation program allows the exploration of many 'what if' type of analyses. In addition the project has produced attractive and potentially useful representations of the possible impacts of climate change at the farm level.

The most interesting research challenge seems to be the establishment of a stronger link of the potential impact of climate change with projected socio-economic changes and the validation of the current model components (suitability maps and related optimised land-use patterns). Such efforts would help to establish the objective non-disputed position of DPI VCCAP in current climate-change related discussions with stakeholders.

A number of additional research themes can be explored with the VCAPP modelling framework that is currently being built. These themes relate to the analysis of current changes, the extrapolation of observed trends, the simulation of future changes and the exploration of what-if type of scenarios. In this way, the framework can also be used in other projects, for example for regional and local government authorities, as part of the strategic planning process.

To strengthen the relation between VU University Amsterdam and the Victorian Department of Primary Industries (DPI) several options exist: exchange of staff members, cooperation in ongoing research activities and the definition of new research projects.

2 Introduction

The implications of climate change are high on the agenda of policy makers and researchers around the globe. The Victorian Department of Primary Industries (DPI), therefore, developed a research program in collaboration with the Victorian Climate Change Adaptation Program (VCCAP). This extensive research program is in many ways comparable to the research efforts that are currently carried out in the Netherlands as part of the Climate changes Spatial Planning (CcSP) research program that started in 2005. Especially relevant in this context is the LANDS project that aims to develop and implement a land-use modelling framework to define and integrate climate adaptation and mitigation measures.

During my visit to DPI as part of their visiting fellow program I was asked to produce a short review to compare the objectives, methods and results of both projects in the hope to provide interesting feedback to DPI VCCAP. The review describes: the general outline, main components, applied methods and preliminary results of both projects, compares them and points at possible future research steps and cooperation options. DPI VCCAP is an extensive research program and the time available for visiting DPI and doing this review was limited so it is not possible to cover all aspects in great depth. Specific attention was therefore given to the land-use related aspects that I am most familiar with. As both projects are still in progress the comparison is based on a snapshot of their current status.

The report is organised as follows. Section 2 describes the objectives, main components and initial results of DPI VCCAP. The following section characterised the LANDS program in a similar way. A comparison of the two projects is presented in Section 4. This section highlights the main similarities and differences and introduces some related research suggestions for DPI VCCAP. The final section draws a general conclusion, suggests a few additional research themes and proposes a number of options to intensify cooperation between DPI with VU University Amsterdam and other Dutch research institutes.

3 VCCAP

3.1 Project aim

The Victorian Climate Change Adaptation Program (VCCAP) is an initiative under the Victorian Government's Sustainability Action Statement (2006), which includes actions for understanding the potential impacts of climate change and developing Victoria's ability to respond.

In collaboration with VCCAP, the Department of Primary Industries (DPI) has developed a research program called DPI VCCAP ensuring Victoria's agricultural industries can adapt to a changing climate. The aim of the research program is to increase the knowledge and capabilities of government, the agriculture sector and farming businesses to undertake sound and informed planning and policy decision that maximise the benefits and minimise the economic, social and environmental costs of climate change.

The influence of climate change on agricultural systems is very complex, requiring a multidisciplinary research approach to develop understanding of the challenges and opportunities. DPI VCCAP has six themes of research and development designed to be integrated and interdependent to ensure a systemic understanding of climate change is developed and communicated.

DPI VCCAP has four key questions guiding its research:

- What are the impacts of climate change on agriculture in regional Victoria?
- What are the climate change adaptation options and likely responses for /of the primary industries in regional Victoria?
- What are appropriate government policy responses to assist the primary industries to adapt to climate change?
- How do we ensure effective communication and utilisation of the information developed by DPI VCCAP?

The following subsections briefly introduce the methodology, its main components and preliminary results. This brief description is based on a number of sources (DPI, 2008; Pelizaro et al., 2009, Sposito et al., 2008) and the presentations and discussions I experienced while visiting DPI-Parkville.

3.2 Methodology

The DPI VCCAP methodology consists of several interrelated components (Figure 1). The starting point in the approach is offered by climate change projections that are based on the well-known IPCC-SRES scenarios. These are elaborated upon by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in 2006. CSIRO prepared for DPI projections of regional climate change at 5 km resolution for 2030 and 2070, for four climate variables (rainfall, minimum temperature, maximum temperature and downward shortwave solar radiation, see Hennessy et al., 2006).

The climate projections are fed into several related research lines related to: land use; agricultural production; and regional hydrology. This review focuses on the land-use theme that consists of the following elements: land suitability analysis; uncertainty analysis; and optimisation. In addition the review will also shortly touch upon the ongoing socio-economic research and activities related to visualisation and stakeholder participation. Each of these five components is briefly introduced below.

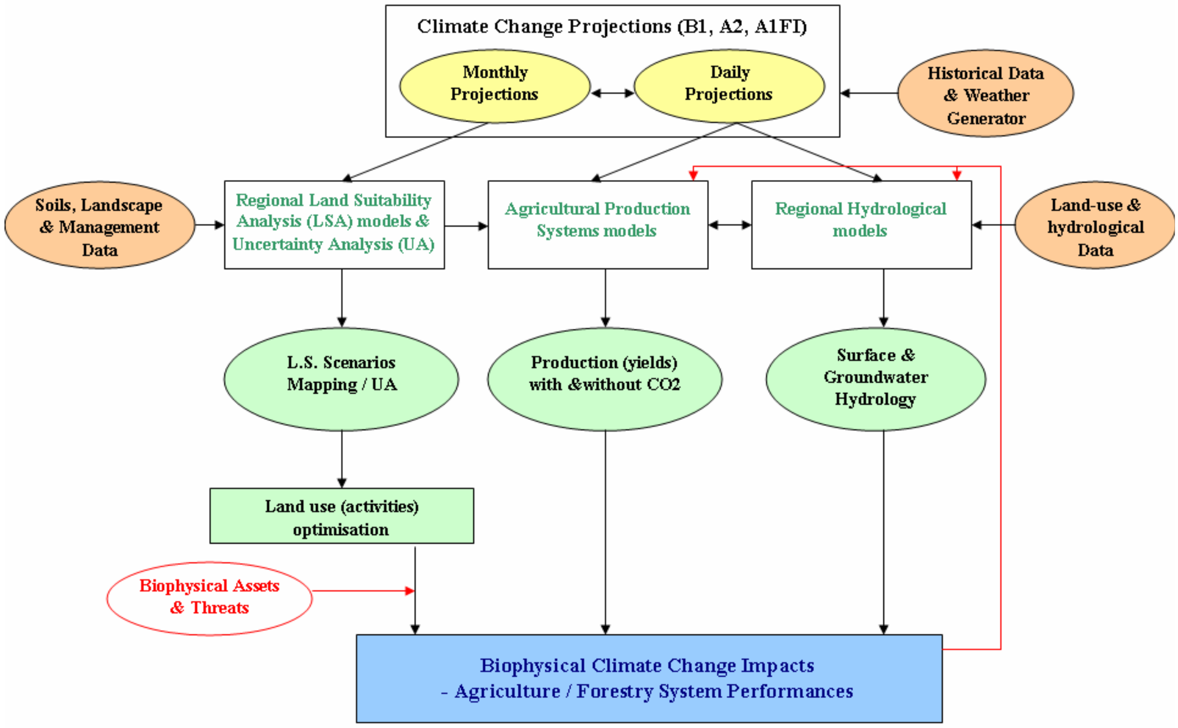

Figure 1 Overview of the main DPI VCCAP project methodology (source: Sposito et al., 2008).

3.2.1 Land suitability analysis

The analysis of land suitability aims to assess the potential of land for specific agricultural commodities. This spatial analysis considers soil, landscape and climate criteria using a specific type of multi-criteria evaluation: the analytical hierarchy process (AHP) developed by Saaty (1980). This method breaks a complex unstructured situation down into its component parts and arranges these "…into a hierarchical order; assigning numerical values to subjective judgements based on the relative importance of each variable (weights); and synthesising the judgement to determine which variable have the highest priority and should be acted upon to influence the outcome of the situation" (Saaty, 1995, p.5).

An interesting characteristic of the approach is that it allows for the assessment of both current and potential suitability taking into account climate changes. In this case projected changes for key climatic variables are derived from the CSIRO scenario elaborations and inserted in the suitability assessment. Currently land suitability is assessed for eight agricultural commodities in a series of workshops with agricultural experts. The commodities are grouped as grains (barley, oats and winter wheat), pasture (lucerne, phalaris and ryegrass/sub-clover) and forestry (blue gum and radiata pine). The weights assigned by the experts to the relevant suitability criteria are used in a GIS-environment to produce a map that represents overall suitability for a specific crop on a relative scale from -1 (restricted from growth) to 10 (100% suitable).

The land suitability analysis can also be used to assess potential yearly yields by multiplying the suitability factor (divided by 10) with the maximum production per hectare per year. Maps with estimated yields for the current (2000) situation were sent back to the experts that helped develop the suitability analysis for a validation of the results. Based on their feedback the weights for the criteria were adjusted and new estimated yield maps were produced until all experts were satisfied with the results.

3.2.2 Uncertainty analysis

DPI VCCAP has analysed the uncertainty related to the degree of land suitability following from the approach introduced above. As this is a purely deterministic approach, the resulting model predictions are point estimates without an inherent indication of error or confidence. A few sources of uncertainty exist, however, in the modelling process. Especially the expert judgement approach to determine the weights introduces certain margin of error/uncertainty to the model. The uncertainty in this case is treated as being related to the variability of the inputs rather than the state of knowledge. This assumption makes it possible to characterise the uncertainty associated with the weights and ratings in the suitability analysis by probability distributions and use serial application of Monte Carlo simulations to produce confidence intervals linked to the predictions. Other metrics for the quantification of uncertainty from the output distribution include variance (error) and percentile data. The numerical simulation-based approach used here is based on previous uncertainty research (Benke et al., 2007; 2008).

The Monte Carlo simulations varied the weight values subject to constraints of range and unit-sum for each level of the hierarchy in the AHP model. Each Monte Carlo simulation experiment in the series was executed over 10,000 iterations and produced, amongst others, confidence intervals and standard deviations for different predicted land suitability values. These uncertainty metrics, typically, have larger values for higher suitability values.

3.2.3 Optimisation

As one of the objectives of the project is to assess potential changes in agricultural land use, an approach was sought to combine the commodity-specific suitability maps into integrated maps showing likely land-use patterns in the future. Specifically, the aim was to determine which crops should be grown at every location across any region in order to optimise the revenue, the fit with land (including soil) suitability, transport costs, conformity with market demands, environmental protection – or any combination of these factors. As application was foreseen on a large area at a high (up to 1 km) resolution, major innovation was deemed necessary.

A solution to this land allocation problem was found in the development of a custom-made computer program that is able to apply a deterministic, probabilistic or genetic algorithm approach to optimise land-use choices. The genetic algorithm technique has the advantage of relatively quickly producing close to global optimal solutions, for problems that are too complex to be solved with more traditional optimisation methods. The computer program developed by Ray Wyatt allows users to specify, for example, market conditions (commodity prices and maximum demand) and see which spatial patterns result from these assumptions and the previously assessed land suitability values. It runs extremely fast on a regular desk-top computer.

3.2.4 Socio-economic research

The socio-economic line of research has started fairly recently and aims to understand the current societal and economic context of the research area. It studies the industry structure, agricultural production values, economic performance of farms and the international and national context. Unfortunately the required statistical data are not very consistent over time. The available information dates back several decades, but only the last 10 years were deemed consistent enough for inclusion in the analysis. Although these data sets are still hampered by inconsistencies, initial research has started to be able to explore recent socio-economic developments. This analysis has delivered basic statistics and maps related to, for example, changes in industrial diversity and agricultural employment.

Socio-economic research has the potential to pinpoint ongoing changes in agricultural production patterns (e.g. changes to new crops) and may help explain observed spatial developments. Results have not yet been published, however, so this line of research is not discussed further in this review. The topic is considered important, however, and deserves full research attention. If possible, a longer time period should be used in this research as that may help to better analyse current trends and understand the driving forces that underlie them.

3.2.5 Visualisation and stakeholder participation

DPI VCCAP is applying three-dimensional (3D) visualisation tools to show the potential impacts of climate change and possible adaptation strategies to policy, decision-makers and communities. Currently a number of visualisation tools are used to depict a future farming systems scenario (2030) in South West Victoria. The developed visualisation products include: digital globes (Google Earth) to generate flythroughs; embedded 360 degree panorama viewpoints; and an interactive online virtual landscape tool known as SIEVE (Spatial information exploration and visualisation environment), developed by the University of Melbourne.

Digital globes such as Google Earth offer a ICT-platform suitable for showing large-scale landscape conditions (past, present and future). The DPI VCCAP visualisation team are currently using Google Earth to show regional modelling outputs produced by the DPI VCCAP Impacts modelling team, such as the land suitability analysis. Such modelling outputs can be viewed and shared using Google Earth. Digital globes provide a powerful window to complex landscape models and can better communicate likely future climate change scenarios to policy, decision makers and communities.

The DPI VCCAP visualisation team has also developed a prototype future farming system scenario for 2030 as a discussion point, envisioning what two neighbouring farms could look like. It is based on a business as usual/traditional approach to farming in contrast to an earlier adaptor who deploys new technologies such a renewable energy measures and land management practices, for example deeper rooted perennials and land-use diversification (e.g. blue gums). The next stage is to further refine these visualisation products and to evaluate their effectiveness as a science communication tool for informing policy decision makers and communities about climate change.

3.3 Preliminary results

The project methodology has been applied to a case study region: South West Victoria. This area was selected because agriculture is vital to the region's and state's economy, representing approximately 20% of Victoria's agricultural production (measured in total gross value in 2003-2004). Moreover, changes in agricultural land use are expected here as a consequence of changes production patterns and climate. A significant amount of land devoted before to cattle and sheep productions is now being used to cultivate a wide variety of grains (e.g. barley, winter wheat and oats), pasture and grasses, as well as forestry.

The project has, thus far, generated a series of land suitability maps and related uncertainty assessments for different agricultural commodities in South West Victoria. An example of which is included here as Figure 2.

The land suitability analyses have been made for 2000 and 2050 taking into account climatic changes. Based on the suitability assessments, average maximum yields, market price, market demand and transport costs optimal land-use patterns are simulated using various mathematical optimisation approaches. A preliminary result, showing a screen dump from the computer program, is included as Figure 3. The program is able to optimize land use for each of the eight agricultural commodities at a 1 km resolution, covering the whole of South West Victoria in about 67,000 cells. The model helps assess the potential impact of climate change on land-use patterns under current or other market conditions.

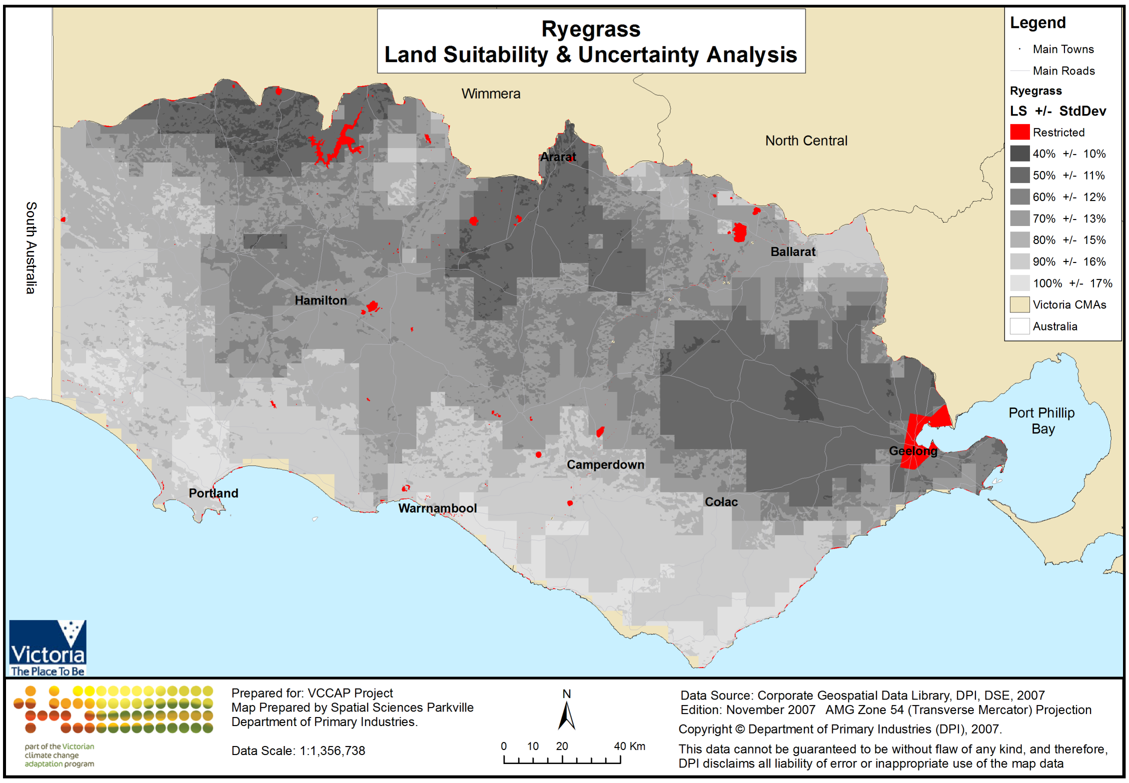

Figure 2 Land suitability and related uncertainty for Ryegrass in the South West Victoria (source: Sposito et al., 2008).

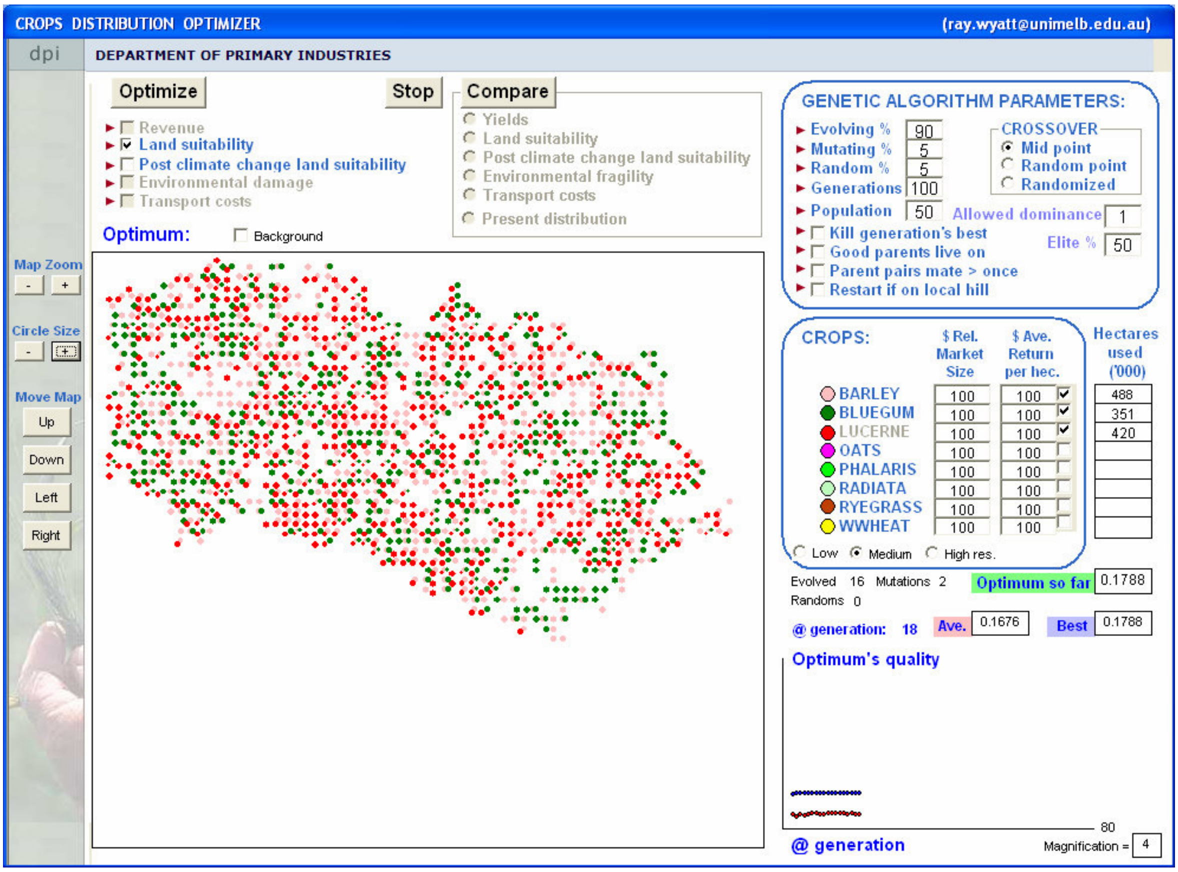

Figure 3 Screen shot from the computer program that optimises agricultural land-use patterns (source: Sposito et al., 2008).

The most striking results of the visualisation efforts are foto-realistic depictions of typical farms in 2030. These digital representations allow the visualisation of the local impact of climate change and related adaptation measures.

Figure 4 Examples of foto-realistic vislualisations showing a farm in the future without (left) and with (right) climate adaptation measures (source: DPI, 2008).

4 Lands

4.1 Project aim

Climatic changes are expected to have important implications for land-use patterns, especially in coastal areas and river basins. In the Netherlands, the substantial research program 'Climate changes spatial planning' aims to develop an adequate and timely set of policies for mitigation and adaptation to cope with the impacts of climate change. This is done in an extensive series of related research projects dealing with, for example, climate scenarios, water management and adaptations in agriculture, nature and inland navigation.

Within the research program the LANDS project identifies climate-change driven land-use developments and integrates these into balanced national visions and regional solutions. Important research questions in this respect are:

- which possible changes are to be expected in the Dutch land-use system as a consequence of climatic changes?
- what spatial adaptation and mitigation strategies are to be developed to minimize this potential impact of climate change to the various societal sectors (agriculture, nature, residences)?
- to what extent will the proposed sector-specific adaptation and mitigation measures offer the potential for synergy or conflict at the local level?

The LANDS project is an extensive, long-lasting research activity that is carried out a by large group of researchers from many fields of expertise located at VU University (SPINlab, Institute for Environmental studies and Faculty of Economics), Wageningen University and Research Centre and the Netherlands Environmental Assessment Agency. The project produces the following components to integrate the results from the other projects in the research program:

- a scenario framework, that consistently combines assumptions related to climate, population, economy and society, forms the common ground for the various adaptation- and mitigation measures;
- a detailed, calibrated land-use model that integrates the sector-specific adaptation measures into simulations of future land use;
- a set of indicators and visualisation applications that supports pinpointing the possible synergies and conflicts in (combinations) of land use.

Currently, the project has resulted in a seriously revised version of the *Land Use Scanner* model that offers an integrated view on all types of land use, dealing with urban, natural and agricultural functions. The model now offers the possibility to use a 100x100 metre grid, covering the land surface of the Netherlands in more than 3 million cells. This resolution comes close to the size of actual building blocks and allows for the use of homogenous cells that describe the single land-use type that dominates a cell. This characteristic makes it easier to communicate the results, for example in the form of 3-dimensional visualisations.

As the main objective and building blocks of the project are very similar to VCCAP project, it offers a very interesting possibility to compare the ongoing research activities in Australia and the Netherlands. The following sections, therefore, introduce those components of the LANDS project that are especially relevant for the VCCAP project. To broaden the scope of this review, the introduction of the LANDS projects also discusses other relevant methods and research projects.

4.2 Methodology

The first step in the LANDS approach consists of the definition of a set of future scenarios that describe potential land-use developments. Obviously, climate change is not the only factor driving land-use change. Socio-economic developments are another major driving force. In fact, these developments interact with climatic changes (Dale, 1997; Watson et al., 2000). For example, economic and population growth cause increased emission of greenhouse gasses, which influence the global climate. As a result, changes in annual regional rainfall patterns could impact agricultural production or cause the tourist industry to migrate to other regions. Prolonged droughts and other extreme weather are other examples of climatic changes that impact the economy.

Integration of climate-change and socio-economic factors is, thus needed in any long-term study on future land-use configurations and related spatial planning measures. However, the scenarios used in most land-use allocation models, are usually neutral to climate change, as only socio-economic factors are taken into account. This assumption appears inappropriate in relation to the expected substantial climatic changes. The project, therefore, starts by defining an integrated set of future scenarios, based on socio-economic scenarios and climate models. These scenarios are used as input in various sector-specific models and are subsequently fed into the *Land Use Scanner* model for an initial simulation of land-use change. In a following phase these results are analysed on their possible adverse impacts on different sectors. Based on this analysis sector-specific adaptation and mitigation measures are drafted that can eventually be fed back into the *Land Use Scanner* to come to an integrated view on possible land-use changes that results from expected societal and climatic developments. This general outline is presented in Figure 5.

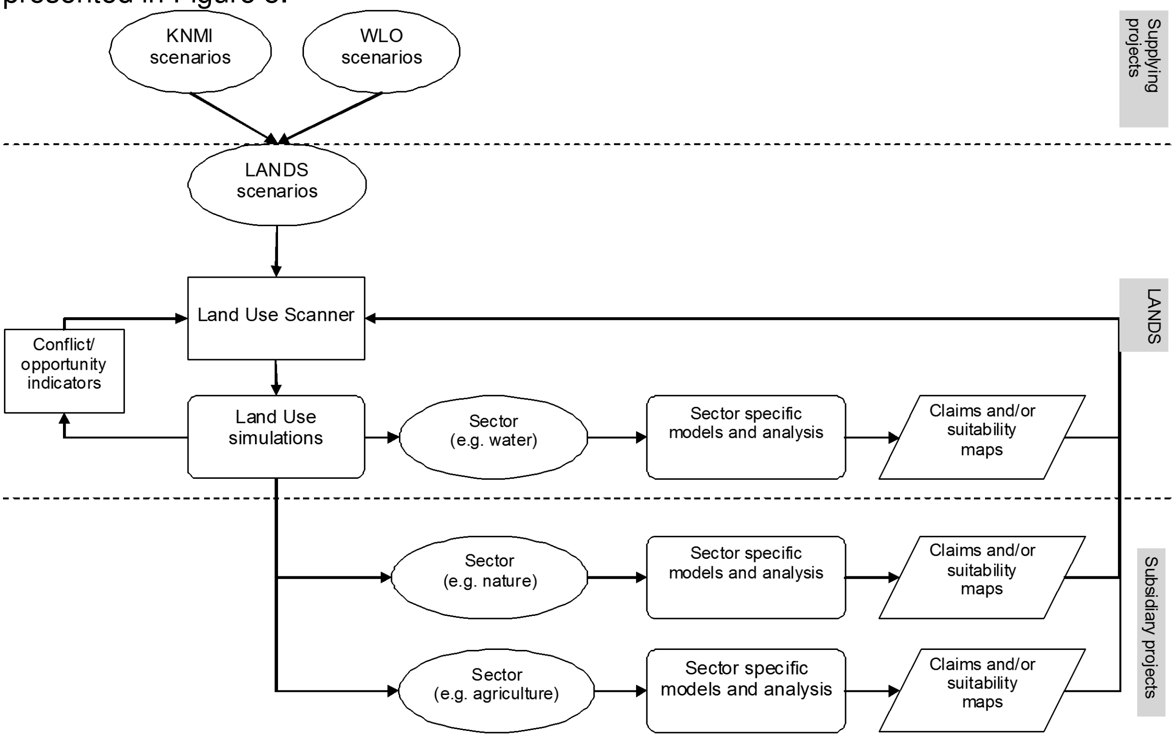

Figure 5 The LANDS project scheme (Source: Koomen et al., 2008).

4.2.1 The *Land Use Scanner* framework

The *Land Use Scanner* is a GIS-based model produces simulations of future land use that are based on the integration of sector specific inputs from dedicated models (Dekkers and Koomen, 2007; Hilferink and Rietveld, 1999). The model is based on demand-supply interaction for land, with sectors competing for allocation within suitability and policy constraints. Land-use simulations are generally scenario driven, with series of coherent assumptions regarding variables such as economic growth or level of government intervention, determining the way the land demand-supply unfolds (Borsboom-van Beurden et al., 2007; Koomen et al., 2005). The renewed model-configuration used for this project applies a 100-meter grid offering a very detailed view on possible spatial patterns in the future. It distinguishes 17 land-use types, out of which the model allocates 11. The remaining six types, mainly related to infrastructure and water, have a pre-defined location that is not influenced by model-simulation. Their location is either a continuation of current land use or consists of pre-defined, approved plans, as is the case with, for example, long-planned railway links. For a more detailed description of the most recent model version and its calibration and validation the reader is referred to other publications (Loonen and Koomen, 2008).

Unlike many other land-use models the objective of the *Land Use Scanner* is not to forecast the dimension of land-use change but rather to integrate and allocate future land-use demand from different sector-specific models or experts. Figure 1 presents the basic structure of the *Land Use Scanner* model. External regional projections of land-use change, which are usually referred to as demand or claims, are used as input for the model. These are land-use type specific and can be derived from, for example, sector-specific models of specialised institutes. The predicted land-use changes are considered as an additional claim for the different land-use types as compared with the present area in use for each land-use type. The total of the additional claim and the present area for each land-use function is allocated to individual grid-cells based on the suitability of the cell. This definition of local suitability may incorporate a large number of spatial datasets referring to the following aspects that are discussed below: *current land use*, *physical properties*, *operative policies* and *market forces* generally expressed in distance relations to nearby land-use functions.

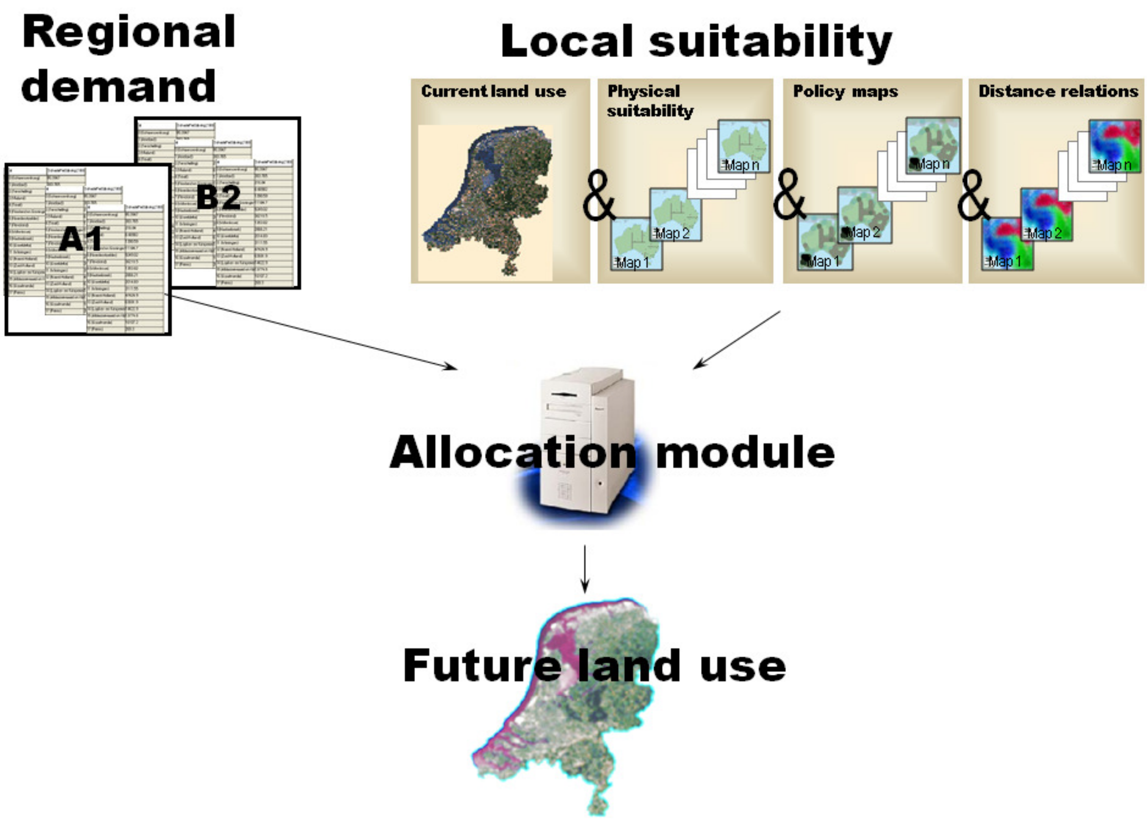

Figure 6 Land Use Scanner layout (Source: Koomen et al., 2008).

Current land use, of course, offers the starting point in the simulation of future land use. It is thus an important ingredient in the specification of both the regional claim and the local suitability. Current land-use patterns are, however, not necessarily preserved in model simulations. This offers the advantage of having a large degree of freedom in generating future simulations according to scenario specifications, but calls for attention when current land-use patterns are likely to be preserved.

The *physical properties* of the land (e.g. soil type and groundwater level) are especially important for the suitability specification of agricultural land-use types as they directly influence possible yields. They are generally considered less important for urban functions, as the Netherlands have a long tradition of manipulating their natural environment.

Operative policies, on the other hand, help steer Dutch land-use developments in many ways and are important components in the definition of suitability. The national nature development zones and the municipal urbanisation plans are examples of spatial policies that stimulate the allocation of certain types of land use. Various zoning laws related to, for example, water management and the preservation of landscape values offer restrictions on urban development.

The *market forces* that steer, for example, residential and commercial development are generally expressed in distance relations. Especially the proximity to railway stations, highway exits and airports are considered important factors that reflect the locational preferences of the actors that are active in urban development. Other factors that reflect such preferences are, for example, the number of urban facilities or the attractiveness of the surrounding landscape.

The selection of the appropriate factors for each of these components and their relative weighing is a crucial step in the definition of the suitability maps and determines, to a large extent, the simulation outcomes. The relative weights of the factors that describe the market forces and operative policies are normally assigned in such a way that they reflect the scenario storylines.

The *Land Use Scanner* model has been thoroughly reviewed as part of an international scientific audit of the land-use models at the Netherlands Environmental Assessment Agency (MNP). The audit committee consisted of internationally acclaimed experts (Michael Batty, Helen Couclelis, Michael Wegener and Harry Timmermans) and concluded "that the *Land Use Scanner* and Environment Explorer are among the best in the field, and are very useful for assessing policy impacts relating to the spatial distribution of land use at the national level" (Timmermans et al., 2007).

4.2.2 Visualisation and stakeholder participation

Visualisations are the key to effective public interaction because they are the only common language to which all participants within the same cultural context – technical and non-technical – can relate (King et al. 1989). Maps are an especially universal way to communicate about spatial developments. Policy makers, for instance, use maps to present their spatial plans to the local community, and scientist use maps to present for example spatial model outcomes to other scientists.

In addition to classic maps in two dimensions, more realistic three-dimensional renditions of projected changes are becoming more popular to communicate results to non-experts. Such 3D-visualisations are more appealing and may be also easier to interpret than traditional 2D maps. A disadvantage is, however, that a 3D virtual environment is normally time-consuming to create. As part of the LANDS project exploratory research was done to find an approach that combines the flexibility of digital, GIS-based map making with the appeal of 3D visualisations. This quest builds upon previous inventories and practical work done in the Netherlands (Borsboom-van Beurden et al., 2006; Riedijk et al., 2006; Van den Brink et al., 2007). The objective was to find a visualisation process that is easy and quick, and a result that is appealing, easy to distribute and interactive. We have developed a process that makes is possible to create 3D visualisations in a quick and easy way. A process is developed to visualisations of the simulated land-use changes specifically for the *Land Use Scanner* model applied in the LANDS project.

Different software tools exist to create features in three dimensions (icons) but we selected the SketchUp software by Google for the following reasons: it allows creating, viewing and modifying 3D representations in a relatively quick and easy way. The software, furthermore, is freeware and thus available without additional costs. However, a professional version exists (SketchUp pro) for advanced users. In our pilot-study, the freeware version was sufficient to effectively create semi-realistic 3D visualisations. The SketchUp tool has the advantage that we did not have to rely on the much more complicated traditional graphic design (CAD) software. It has the further advantage of being closely linked to both the GIS-software from which we export the locations of changed land use and the GoogleEarth tool that we want to use to show the final visualisations.

We have chosen to represent the locations of land-use change in three dimensions for the following *Land Use Scanner* classes:

- *Low density residential areas:* single family dwellings with a maximum of three floors.
- *Medium density residential areas:* multi-family dwellings consisting of low apartment blocks of four to five floors.
- *High density residential areas: high rise* apartment blocks of about 10 floors
- *Commercial areas:* office buildings and other districts with big and small buildings
- *Greenhouses*: horticulture in greenhouses

The changed locations of the other simulated land-use types (nature/forest, agriculture and recreation areas) will be shown as two dimensional squares. For the land-use types that are not simulated by the model (infrastructure and water) no additional visualisations are created. Together with the other locations of no-change these will be represented through the GoogleEarth aerial photo base maps in the final visualization.

The 3D-design of the new land-use type icons in 2040 has been done according to criteria listed below. First, we strived to create semi-realistic icons that are made to *scale*. This means that the built 3D land-use types will correspond to the 100x100 metre size of the pixels that form the grid. So, for example, buildings that have a height of 10 metres will take up 10 percent of the length and width of the grids. An additional concern is that we want to represent the *future.* This means that the design should have a somewhat futuristic tendency, depicting houses as they may look like in the coming decades. Last, but not least, the visualisation must allow a constant speed over the whole represented area, thus strongly limiting the *file size* of the individual icons. This means that the elaboration of 3D land use will be conditioned, a priori, by avoiding maximum detail in the buildings, working with “Textures” which allows the painting of the created facades, and storage in “Components”.

In a second step we add the 3D-icons to the locations of changed land use. Starting-point in this process are the raster-grid results (ASCII-files) from the land-use model that describe, for each land-use type, the new locations. These locations are obtained from the model by comparing the 2040 land use with the current situation at a pixel-by-pixel basis. The land-use grids are then imported in a desktop GIS (ArcGIS) and converted to georeferenced points (shapefiles). These are then exported to SketchUp where every cell (it is the pixel with the land use type information) will be replaced with the created 3D icons. The SketchUp ArcGIS plugin allows conversion of the ArcGIS data vector geometric features to .SKP file for SketchUp. We can export polygons that result in a group of edges, vertices and faces in SketchUp, and we can export also polylines that they will be a set of edges and vertices, and, most importantly, we can export points.

The new SKP files will keep the georeference and size information from ArcGIS. These points will in SketchUp be depicted as small crosses that we will later replace with the 3D land use created. See Figure 7 for an overview of this process.

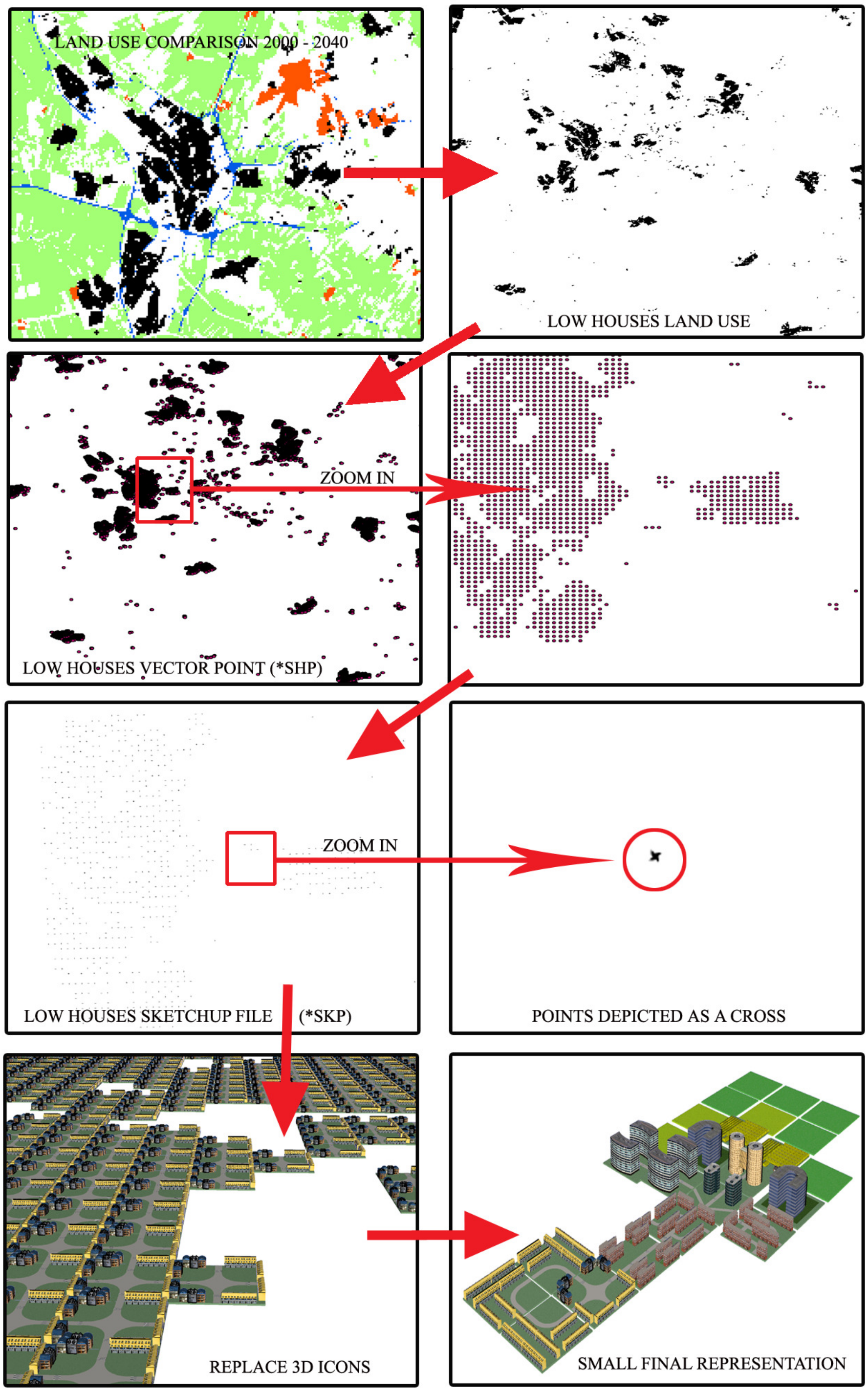

Figure 7 Graphic representation of the visualisation process.

Another research initiative to enhance stakeholder participation concerns the *Touch Table*. The potential of this device to support collaborative group processes is explored in the LANDS project and other climate change related research and planning projects. The *Touch Table* projects (spatial) information on a table-like surface and allows users user to interact with the projected information. They can manipulate the image (pan or zoom), add additional information (draw or type), or start specific applications features on the map. The table has multiuser and multi-touch capabilities: all users around the table can interact at the same time. The *Touch Table* can be applied in every kind of collaboration where spatial data is needed, for example in spatial planning processes or in disaster management situations.

The device has, for example, been applied in a public participation project that aimed to collect local information from citizens for a strategic planning document (Figure 8). Other projects aimed at interactive land-use planning at the local level (Arciniegas et al., 2008) and designing climate-proof regional spatial plans.

Current research related to visualisation and participation aims at creating and applying functioning tools and evaluating their effectiveness. This research follows previous Ph.D. studies that evaluated the added value of spatial information and spatial decision support systems (e.g. Dias, 2007; Fabbri, 2002; Uran, 2002).

Figure 8 Using the Touch Table to collect local information for a strategic planning document.

4.3 Preliminary results

Central to the LANDS project is the revised and now calibrated *Land Use Scanner* model with its implemented socio-economic scenarios. This has been developed in the past years and has now been described in various publications. The key result of this initial part of the project consists of a set of detailed (100 metre grid) scenario-based simulations of future land use (Figure 9). We are now in close contact with various climate adaptation projects to incorporate our land-use simulations in their work and integrate their adaptation measures in a next set of simulations. Within the LANDS project we specifically look at possible adaptation measures related to water and nature management.

Together with the Dutch Agricultural Economics Research Institute (LEI) we are currently analysing the potential for second generation bio-fuel crops as a potential mitigation and adaption option. This research aims at defining suitability maps that indicate yield potential (as percentage of maximum yield) for bio-fuel crops. Based on the potential yields and projected crop prices (that are related to fuel prices) the profitability of this crop relative to others is assessed. This relative profitability then steers the land-use choice, implying that bio fuel crops will outcompete other less profitable crops.

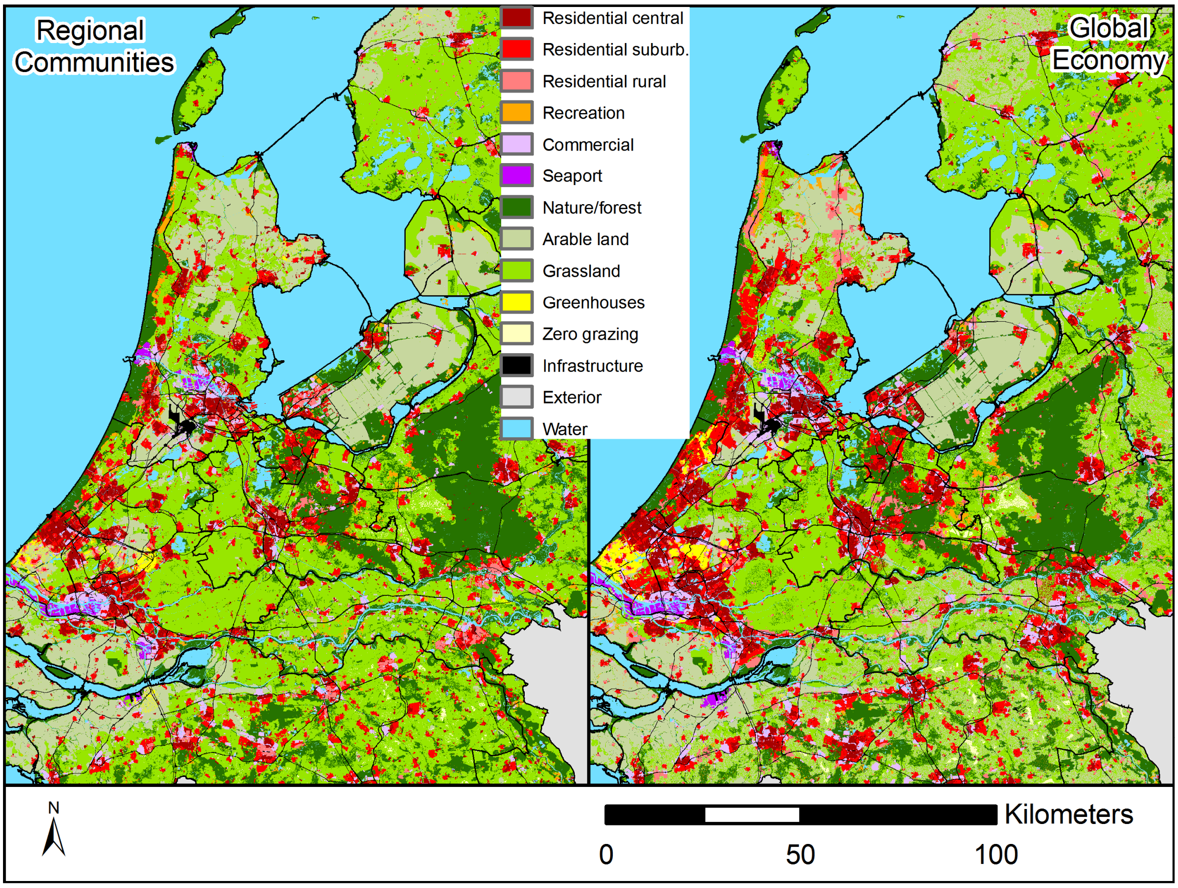

Figure 9 Simulated future land use in 2040 for two socio-economic scenarios in the LANDS project.

To better interpret and present the results we have developed specific indicators and visualisation options as was discussed in the previous section. Most of the research is done as part of PhD trajectories, but a close connection to the non-academic world is also pursued. Involvement of local and regional stakeholders is important to make sure that we are correctly incorporating the relevant developments in the different societal sectors (nature, water, agriculture et cetera). This involvement mainly takes place in the sector-specific projects.

The modelling framework and knowledge applied in this research project are also used in other, more practical projects related to spatial planning at different scale levels. In 2008 land-use simulations have been generated for various regional authorities in the Netherlands as part of their strategic planning documents. Climate related land-use impacts such as flood risk have been assessed in these project using indicators developed in the LANDS project. In 2009 the *Land Use Scanner* will be combined with the Clue-s model to produce land-use simulations for the European Community (DG. Environment and Joint Research Centre). These simulations will aim to assess the potential land-use related impacts of a new bio-fuel directive, climate change and transport policies.

5 Comparison

The DPI VCCAP and LANDS research projects share a common objective: understanding the potential impacts of climate change on land use and helping develop adaptation measures to respond to the changed situation. This section discusses the main similarities and differences between the two projects. Based on this comparison some initial suggestions for further research at DPI are discussed. These relate directly to the topics discussed here. The following, final section of this review briefly introduces some more general research themes for DPI to consider.

5.1 Similarities

Both projects make use of scenario-based climate projections that are based on the IPCC SRES scenarios. In both cases detailed, well-elaborated regional projections of changes in key climatic variables are available from renowned institutes. This offers a solid base for subsequent impact assessments.

Oddly enough, the sizes of the study areas (South West Victoria and the Netherlands) are roughly comparable. Modelling the whole state of Victoria would obviously be much more demanding, but detailed land-use simulations for such large region are now feasible as recent research projects (Verburg et al., 2006; Verburg et al., 2008) and our current efforts for the European Commission prove.

The definition of suitability is key to the land-use allocation methods in both projects. The land suitability assessments for agricultural commodities in Victoria follow a robust approach. In character and included criteria the resulting maps are comparable to the yield potential maps developed by the Dutch agricultural Economics Research Institute (LEI). The individual land suitability maps for Victoria were validated in expert sessions. A more quantitative validation approach with observed local yields per crop would be welcome, however, to test the degree in which they are able to predict yields in current climatic conditions.

The DPI approach to produce land suitability maps neatly incorporates the potential impact of climate change, thus offering a good starting point to assess potential changes in agricultural land use. This assessment is done with a sophisticated, custom-made optimisation program that offers great flexibility in specifying market conditions and other relevant criteria for land-use allocation. This program allows the exploration of many what-if type of analyses (e.g. which agricultural land use patterns are likely to result from climatic changes under current economic conditions). This approach is comparable to the *Land Use Scanner* approach in its application of mathematical optimisation techniques and emphasis on the exploration of what-if type of scenarios.

The LANDS project has produced a number of scenario-based simulations of future land use with a calibrated land-use model. To simulate comparably probable future land-use patterns in Victoria corresponding to specific scenario conditions two research steps are suggested:

- link the specification of the market conditions to the socio-economic scenarios (e.g. A1F1) that also underlie the climate projections. Especially the use of more elaborate agricultural-economic models that incorporate the international relations between supply and demand for agricultural crops will help improve the internal consistency and robustness of land-use projections. An example of such a model is offered by the GTAP/LEITAP model (see, for example, Eickhout et al., 2007; Van Meijl et al., 2006).

- compare the optimised agricultural land-use map for current climate conditions with actual observed agricultural land-use patterns to validate the approach and possibly increase the confidence in simulations of future land use. Such a validation effort requires a recent land-use map that is comparable in its spatial, temporal and thematic resolution to the optimised land-use maps. The lack of a current, coherent reference map hampers the possibility to adequately assess current and potential land-use changes. The creation of such a map at DPI or elsewhere would thus be a much-appreciated research effort.

The visualisation research at DPI has produced very attractive and useful representations of the possible implications of climate change. The focus on stylised, individual farms to represent archetypal changes in great detail, rather then trying to semi-realistically visualise potential changes in much larger areas as was attempted in the LANDS project, seems to offer a good starting point for communication with stakeholders. It offers an interesting research direction for our work in the Netherlands and we are very interested in the upcoming evaluations of their effectiveness.

5.2 Differences

The main differences between the two projects relate to the different socio-economic and physical context in which the land-use change processes take place. Even the relatively small-sized state of Victoria is extremely large and empty compared to the Netherlands. The harsh climatic conditions, limited availability of water, abundance of space and vast distances in Victoria contrast strongly with the situation in the Netherlands and most parts or Europe.

Other obvious differences between the projects relate to:

- the data availability that seems to be much more limited in Victoria;
- the spatial solution that is somewhat coarser in Victoria (1km) than in the Netherlands (100m);
- the inherent focus on agriculture and forestry at DPI versus the more integrated outlook on all types of land use (including urban and natural types of land use) in the LANDS project.

The current suitability analysis performed by DPI relies on physical, chemical and biological and does not incorporate social, economic or crop management criteria that are prominent in the LANDS approach. The DPI approach does not directly include issues such as: local availability of non soil-related production factors (capital, labour, knowledge); distance to market or processing plant; required minimum farm dimensions for certain crops; land ownership; management practices; and future market prospects. The currently obtained yields, for example, are based on common practices and do not reflect local differences in the (lack of) effort farmers can put in their crops. Inclusion of non-biophysical criteria in the suitability assessment or subsequent analyses will broaden their potential for realistic land-use simulations.

The uncertainty analysis applied in DPI VCCAP provides a thorough insight in the degree of confidence associated with the estimated individual suitability values. A similar effort would be very welcome in the LANDS project, were such sensitivity analyses have not been performed. However, as Benke and others rightly state, it is good to note that the overall uncertainty of the resulting land-use projections can be larger than described for the suitability values for the individual commodities. This is related to the fact that initial errors may propagate and additional errors may be added in subsequent research steps.

DPI VCCAP, furthermore, has a strong focus on informing and incorporating stakeholders. This open attitude towards the outside world seems to be more strongly emphasised here than in the LANDS project. This approach is much admired and considered important. It must be difficult at times to engage in communication, seeing the controversial nature of the climate debate in many countries. Government research institutes have an important role in this debate to provide objective and undisputed information. The various validation efforts hinted at above should be seen from this perspective. By validating the individual components of the research approach confidence can be expressed in the overall outcomes.

6 Conclusion

Research on climate change, its implications and potential adaptation measures covers many different topics (climate, physical environment, socio-economic conditions, scenario development and planning) and thus calls for contributions from a wide range of disciplines. Such research can not be done in a single, isolated project, but requires a substantial effort of many different scholars and interaction with other relevant research institutions.

DPI VCCAP is a fairly complete research program that covers the most relevant aspects of climate change in relation to agricultural land use. The most interesting research challenge seems to be the establishment of a stronger link of the potential impact of climate change with projected socio-economic changes and the validation of the current model components (suitability maps and related optimised land-use patterns). In addition to the more specific research suggestions described in the previous section a number of more general research themes is mentioned here.

6.1 Additional research themes

The additional research themes suggested here build upon current progress in DPI VCCAP and they are arranged by different, essentially subsequent steps in land-use change research (Figure 10). Each individual step (analysis, extrapolation et cetera) is illustrated with one or more example. A prerequisite for this type of analysis is the availability of land-use maps, preferably describing subsequent time steps.

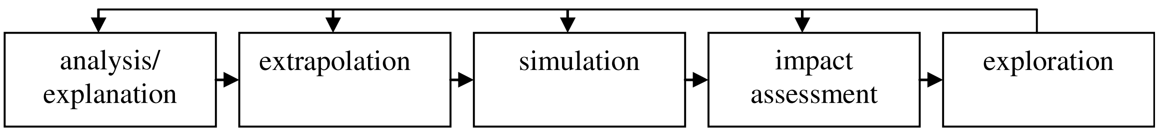

Figure 10 Subsequent steps in the planning related research process.

Analysing and explaining the magnitude and location of past land-use changes is a logic first step in starting any study on potential changes in land-use. This relates to questions such as:

- can we indeed observe an increase in forest cover in Victoria as some scholars claim?
- do we see a conversion of agricultural land?
- how much land is claimed annually by urbanisation and where is this process particularly strong ?

A thorough analysis of recent trends should be followed by an attempt to explain these developments, either through the consultation of relevant experts and/or additional statistical analysis.

Extrapolation of the observed trends allows for the assessment of potential developments. Although past developments offer no guarantee for future developments. This type of research can answer questions such as: do prime agricultural areas face urbanisation risk?

Simulation of possible future land-use patterns becomes possible when current processes are understood and formally described in a model of land-use change. In combination with scenario analysis this approach can help answer questions such as: what are the most likely locations for specific types of agriculture taking into account climate change?

Based on simulations of land-use change it is possible to assess potential land-use related impacts, dealing with issues such as:

- can an increase in groundwater use be expected ?
- do we foresee changes in ecological diversity?

A last option in this line of research is the exploration of planning-related what-if scenarios dealing with questions as:

- what would happen when groundwater prices would rise?
- how would an urban growth boundary affect land-use patterns?
- what would the impact be of changes in agricultural commodity prices?

6.2 Cooperation options

Several options exist to strengthen the relation between VU University Amsterdam and the Victorian Department of Primary Industries (DPI) as is discussed below.

Exchange of staff members: the VU University Amsterdam is happy to receive staff members from DPI, provide them with a temporal work spot and cooperate in their research efforts. Nu funding for such visits exists at VU, however, to cover travel expenses or accommodation costs for visitors. Alternatively various VU staff members are most certainly willing to participate in an exchange program with DPI. Students of the VU may also be interested visit DPI and, for example, write their thesis in Australia as part of ongoing research projects at DPI. Students can be expected to cover most of their expenses from their own or VU sources.

Cooperation in ongoing research activities: as the research interests of DPI and VU overlap, cooperation in ongoing research activities seems mutually beneficial. This overlap relates especially to themes such as:

- the evaluation of the effectiveness of visualisation and participation tools;
- the integrated assessment of land-use changes;
- the definition of climate adaptation measures.

The following activities can be employed to make this cooperation more substantial:

- sharing (drafts of) recent papers and reports;
- linking each other to relevant contacts and information sources; VU can introduce DPI to various European researchers and institutes, while DPI can provide the same services in the Australian context.
- exchanging research tools as was already done with the *Land Use Scanner*, land-use change analysis exercises and crop optimizer model;
- co-authoring research papers; especially review type of papers or comparative studies can be written together;
- participating in each others activities; VU could, for example, coach or assist in the analysis of land-use change in Victoria or specification of a new *Land Use Scanner* application.

Definition of new research projects: the joint definition and procurement of new research projects is an interesting opportunity to further strengthen the relations between DPI and VU. The difficulty here might be, however, that few funding possibilities exist that would enable such research projects.

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